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by David I. Blumenstock and Daniel F. Rex,

with a special section on Vegetation

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THE PACIFIC SCIENCE BOARD
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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past thirteen years.

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Correspondence concerning the Atoll Research Bulletin should be addressed to the above

c/o Pacific Science Board
National Research Council
2101 Constitution Avenue, N. W.
Washington 25, D. C., U.S.A.

FOREWORD

The Eniwetok Microclimatic Project was established in the summer of 1957 under the joint auspices of the University of Hawaii, the U. S. Weather Bureau, and Joint Task Force Seven of the U. S. Department of Defense. The ultimate goal of the project was to determine to what extent a deep, large atoll in the open ocean trade wind zone creates its own weather and climate.

This report, originally issued to a restricted distribution list by Joint Task Force Seven as JTFMC TP-16, December 18, 1959, is essentially a data report. It presents the observational findings from which some answers to the basic inquiry can be deduced through further investigation.

Since the data presented are of basic significance for the study of coral atoll ecology and are of great interest to the Coral Atoll Program of the Pacific Science Board, they are being made generally available as an issue of the Atoll Research Bulletin.

Editors

The University of Hawaii, the U. S. Weather Bureau, and Joint Task Force SEVEN each provided funds, equipment, and personnel in support of the study. In addition to the senior authors, those participating in the observational program at Eniwetok were:

1.	Mr. Dominic D. Conte	Pacific Supervisory Office U. S. Weather Bureau, Honolulu, Hawaii
2.	Mr. Wilson Floe	Pacific Supervisory Office U. S. Weather Bureau, Honolulu, Hawaii
3.	S/Sgt. F. E. Haas, USAF	JTF SEVEN Meteorological Center Pearl Harbor, Hawaii
4.	Prof. Irwin E. Lane	Botany Department, University of Hawaii Honolulu, Hawaii
5.	Mr. Tetsuo Matsui	Botany Department, University of Hawaii Honolulu, Hawaii
6.	Mr. Mikihiko Oguri	Botany Department, University of Hawaii Honolulu, Hawaii
7.	Prof. Jimmie Bob Smith	Botany Department, University of Hawaii Honolulu, Hawaii

Without the excellent work of these field personnel and the outstanding support of many other persons in the sponsoring agencies and the U. S. Atomic Energy Commission it would have been impossible to conduct this study. We wish to express our sincere thanks to all those concerned with the project for their genuine interest and valuable assistance. In particular we wish to acknowledge the active and continuing support provided by Mr. Ernest Wynkoop and Mr. Ray C. Emens of the U. S. Atomic Energy Commission and Professor Doty. We also wish to thank Professor Irwin Lane for his special field investigation of the distribution of vegetation on two of the islets of Eniwetok and for his preparation of one of the principal sections of this study. Finally, we wish to thank the personnel of the USAF Air Weather Service detachment at Eniwetok, who made radarscope and other special observations in direct support of this study.

David I. Blumenstock

Daniel F. Rex

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MICROCLIMATIC OBSERVATIONS AT ENIWETOK

1. INTRODUCTION

For a one-year period, from August, 1957, to August, 1958, the authors together with their other field colleagues conducted a study of microclimatic conditions at Eniwetok Atoll in the Marshall Islands. The primary purpose of the study was to determine to what extent a deep, large atoll lying far at sea in a trade wind zone creates its own weather and climate. Stated differently, how and to what degree do the weather and climate of Eniwetok differ from the weather and climate that would obtain if there were only open ocean where Eniwetok lies?

This report on our study does not attempt to answer the fundamental question raised above. Instead, it merely presents our observational findings. It is a data report, designed to make available to meteorologists and others data that we hope will be useful to them in many different kinds of inquiries.

We are including in this report not only the data themselves, together with information concerning the observational sites and procedures used, but also a modicum of information concerning the nature of the atoll and of broad-scale weather conditions in the Eniwetok area. This additional information is provided to make our results most useful to as many different investigators as possible, including those unfamiliar with Eniwetok and with the Marshall Islands Atoll area.

Since the observational plan of this study is described in detail in Section 7, all that will be done here is to indicate its nature in very broad terms. During two different two-week periods, one during August, 1957, and the other during January-February, 1958, weather observations were made at seven different sites in the atoll. These sites were on the islets of FRED, BRUCE, KEITH, ELMER, JANET, and YVONNE; and also in the lagoon at MACK[1]. (<u>See</u> Figure 1.) At FRED there were hourly observations, made by the USAF, Air Weather Service. At BRUCE and KEITH, observations were 3-hourly. Elsewhere, observations were made daily.

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[1] For convenience, American code names are used for most islets and reefs referred to. Both code names and native names appear in Figure 1.

Observations varied from site to site, but among the sites they included all the usual kinds of surface weather observations and also rawinsondes twice daily, cloud photographs, and radarscope photographs. During these two 2-week periods observations were also made on trans-lagoon runs aboard an M-boat (LCM) and on ocean runs outside the reef in an aircraft rescue boat (ARP). On lagoon and ocean runs surface water temperatures were measured through making bucket hauls at frequent intervals.

During the remainder of the year, outside these two intensive-study periods, the observations were restricted to the usual comprehensive hourly observations at FRED and to daily, semi-monthly, and monthly rainfall observations at various other sites[2]. Circumstances did not permit making regular rainfall observations

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[2]Except for the intensive-study periods, only the daily rainfall values are presented for FRED. Sources of other data for FRED are given in Appendix III.

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throughout the entire year at all of the sites listed above. It is hoped nonetheless that the observations obtained will be found to be useful in supplementing the observations for the two intensive-study periods.

Those who wish to use the primary data appearing in Appendix I or listed in Appendix II may find Appendix III helpful to them. Appendix III lists several major sources for additional meteorological data for Eniwetok.

2. GENERAL GEOGRAPHIC RELATIONSHIPS[3]

Eniwetok is situated in the Marshall Islands, a group of islands lying north of the Gilbert Islands and east of the Caroline Islands. It is located at 11.4°N., 162.3°E. Most of the atolls which make up the Marshall Islands are distributed along two chains which are nearly parallel and trend northwestward.

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[3]A large part of the factual information contained in this section was obtained from "Geology of Bikini and Nearby Atolls" by Emery, Tracy, Ladd et al, USGS Prof. Paper No. 260-A, Part I, 1954. The reader is referred to this publication for a more detailed presentation.

The easternmost is the Ratak (Sunrise) Chain; the westernmost, the Ralik (Sunset)

Chain. In addition to these two main chains there are several isolated outlying atolls. Altogether the group contains twenty-nine atolls, five islands having no interior lagoon and two, known, submerged banks shallower than ten fathoms. The highest land elevation within the group is about twenty-eight feet.

Eniwetok is an isolated atoll lying west of the Ralik Chain and is located some 2,500 statute miles west-southwest of Honolulu, Hawaii and some 4,700 miles from San Francisco. The atoll is some 190 statute miles due west of Bikini Atoll, which together with Ujelang, located some 130 miles southwestward from Eniwetok, are the closest exposed land areas. It appears that Eniwetok Atoll was originally a volcanic cone, since basalt was found there in 1950 as a result of several deep drilling explorations. The cone probably initially emerged some feet above the water and later was eroded away and absorbed by wave and water action. When the critical depth of sea water required for coral existence and growth was reached by the emerging cone, coral growth probably began.

Today Eniwetok Atoll consists of a chain of about thirty small, low islets surrounding an oval lagoon 25 miles long by about 20 miles wide (Figure 1). The total dry-land area of these islets is only 2.5 square statute miles compared with a total lagoon area of 360 square statute miles. The total reef area exposed at low tide is about 32 square statute miles. Most of the islets are less than 13 feet high but are, in some instances, covered by coconut palms reaching up to 80 to 100 feet above low tide level. Three entrances penetrate the reef. Deep Entrance at the southeast side is only about 3/4 of a mile wide but it has a depth of 31 fathoms between ELMER and Japtan Islets (Figure 1). South Channel, on the other hand, is very wide, about six miles, and is usually known as Wide Passage. Charted depths in Wide Passage are only 6 to 12 fathoms. Southwest Passage on the west side is even shallower, having depths of only about 1 fathom. Maximum tidal currents of two knots in Deep Entrance and of 1 knot in Wide Passage have been observed.

The Eniwetok lagoon is nearly elliptical with its long axis trending northwestward. The deepest area is in the north central part of the lagoon, which is the area farthest from the main passes through the reef (Figures 1 and 2). If the numerous superimposed coral mounds were ignored, the bottom contours would show a smooth slope from depths of about 24 fathoms near FRED northwestward to the deepest point of the lagoon, about 35 fathoms. There appears to be no

indication whatsoever of submerged terraces or cliffs on the deep portion of the lagoon floor. The mean depth of the lagoon is 26.2 fathoms, with depths between 24 and 32 fathoms most common. Bottom samples and underwater photographs show that the lagoon floor is chiefly covered with Foraminifera, shells, Halimeda debris, coral and other miscellaneous fine debris.

In the Marshalls, the atolls rise out of water about 15,000 feet in depth. The slopes of the atolls are steepest in the upper portions near the surface. At Eniwetok the contour gradient reaches a rate of about 4,000 feet per mile. Figure 3 shows the ocean bottom contours in the vicinity of Eniwetok Atoll.

The original native population of Eniwetok Atoll was Micronesian and in 1930 consisted of 121 inhabitants who raised chiefly pigs, chickens and coconuts, and caught the abundant fish available in the Eniwetok area. In 1947 Eniwetok Atoll was selected for an expansion of the permanent Pacific Proving Ground because of its isolated position, stable weather and the geography of its land masses. At this time the Eniwetok people were moved to Ujelang, where nearly 200 natives live today. Since that time Eniwetok has been populated exclusively with American personnel associated with atomic test operations. The number of persons present varies from tens of thousands during active operations to several hundreds during interim periods. The development of the atoll for test purposes has consisted principally of the construction of permanent base camps on FRED and ELMER Islets and of the utilization of the northern islets, extending from Runit to Bogallua, for shot-site and technical instrumentation purposes.

3. GENERAL WEATHER SETTING

Although detailed studies of the macroclimate of the Marshall Islands area and of Eniwetok in particular are available in the literature (Appendix III), it was thought desirable to include in this report a general description of the weather setting of Eniwetok. It is the purpose of this section to present a general description that will be especially useful to those not familiar with tropical meteorology.

Eniwetok is located on the south side of the Pacific high pressure belt, in what is commonly called the north-east trade wind zone, and to the north of the equatorial trough of low pressure.

Wind Structure. Eniwetok is overlain with three nearly independent wind

systems. The lowest of these, extending from the surface up to about 20,000 feet, is the well known trade wind current. The Trades are deepest and strongest during the winter months, December through February, with an average strength at the surface of about 18 knots from an east-northeasterly direction. Maximum speeds occur at about the four to five thousand foot level, where speeds greater than 25 knots are not uncommon. The top of the current during this season may often extend to 30,000 feet or more. During the spring and summer the Trades become gradually weaker and more variable. At the same time their average or most typical direction veers from east-northeasterly to easterly. During August and September the average surface wind is 11 knots from the east. During these two months, frequent periods of very light winds, especially coming from the southeast, are often observed. During March, April and May the trade wind current becomes shallowest, often not extending above the 8,000 or 9,000-foot level. Figure 4, on which is plotted the zonal or east-west component of the wind as a function of height and of month, shows these different changes. Surface wind statistics by month are given in Table I.

Above the trades and extending up to the tropopause, which is generally located between 55,000 and 60,000 feet, are westerly winds which are usually called the Upper Westerlies. This wind stream may be thought of as the southward extension of the strong circumpolar jet stream of mid-latitudes. At the latitude of Eniwetok this southward extension of the polar westerlies overlies the trade wind current. The Upper Westerlies are quite variable due to the presence of numerous cyclonic and anticyclonic vortices which are typically carried along in the basic current. Such a vortex, in the proper position relative to Eniwetok, often produces east winds for periods of two to four days at these upper levels. The upper westerly current, whose core is normally located at about the 40,000-foot level, is strongest in the spring, from the month of March through May, at which time average velocities reach 25 knots. At the same time this current is deepest and most well developed. As the season progresses through summer into autumn, the thickness and strength of the current diminishes to average values of about 5 knots with extremely high variability. In mid-winter the Upper Westerlies often do not extend as far south aloft as Eniwetok.

Above the tropopause and situated in the lower stratosphere is the third wind stream, which is an easterly and very steady current. These winds are

TABLE I. CLIMATOLOGIC DATA SUMMARY, ENIWETOK[1]

	TEMPERATURE			PRECIPITATION[2]			SURFACE WIND[3]									SKY COVER				
	OF						% OCCURRENCE									% OCCURRENCE				MEAN
	Mean Maximum	Mean Minimum	Mean Diurnal Range	Mean (inches)	Mean No. of Days with Meas. Precip.	Amount Occurring Most Frequently (inches)	NE	ENE	E	ESE	SE	4 - 12 (MPH)	13 - 24 (MPH)	25 - 31 (MPH)	Mean Speed (MPH)	0 - 2 (Tenths)	3 - 5 (Tenths)	6 - 9 (Tenths)	10 (Tenths)	(Tenths)
JAN	84.6	77.7	6.9	0.95	11.4	.02-.05	33	45	20	1	0	11	74	14	18.7	19	40	25	16	5.4
FEB	84.4	77.5	6.9	1.09	8.4	.02-.05	27	56	15	0	0	14	74	11	18.4	18	33	24	25	5.9
MAR	84.6	77.8	6.8	1.62	12.1	.02-.05	20	60	14	3	0	14	77	9	17.8	14	32	27	27	6.2
APR	85.6	78.7	6.9	1.13	9.6	.02-.05	21	63	15	1	0	8	85	7	18.4	15	27	24	34	6.5
MAY	85.5	78.7	6.8	4.80	15.0	.02-.05	13	59	24	3	1	15	78	6	17.5	10	27	28	35	7.0
JUN	85.9	78.9	7.0	3.88	15.4	.02-.05	12	59	24	3	1	16	79	4	16.9	11	33	41	25	6.3
JUL	86.1	78.9	7.2	6.01	19.1	.11-.25	8	38	35	10	4	38	59	1	13.7	9	34	37	20	6.6
AUG	86.3	79.1	7.2	6.93	20.9	.11-.25	9	27	35	9	8	48	45	1	11.9	6	29	41	24	7.0
SEPT	87.0	79.4	7.6	6.44	16.6	.26-.50	10	20	37	6	6	55	39	1	11.2	9	32	36	23	6.6
OCT	86.7	79.1	7.6	7.96	20.4	.11-.25	14	27	29	8	7	52	42	1	11.7	7	27	38	28	7.0
NOV	86.0	79.0	7.0	5.89	18.7	.02-.05	16	42	28	7	3	32	58	8	15.8	13	39	29	19	6.0
DEC	85.1	78.7	6.4	2.50	15.6	.02-.05	26	45	24	2	1	20	66	11	17.7	17	38	24	21	5.7
ANNUAL	85.7	78.6	7.1	49.20	183.2	.02-.05	17	45	25	5	3	27	65	6	15.8	12	33	30	25	6.3

1 Based on observations July 1945-March 1947; June 1949-July 1955, less May 1951.

2 Measurable precipitation is taken as being 0.01 inch or more. The intervals used for tabulating the frequency of rainfall amounts were 0.01, 0.02-.05; 0.06-.10; 0.11-.25; 0.26-.50; 0.51-1.00; and over 1.00.

3 Winds from directions other than those shown occurred less than 5% of the time on an annual basis; windspeeds above 31 m.p.h. occurred less than 1 percent of the time.

normally called the Krakatoa Easterlies. The Krakotoa Easterlies are weakest during the winter months of December through February and reach their maximum strength in the late summer or early autumn from August to October. Lack of observational data precludes any positive statement concerning their extent. However, they are generally observed above altitudes of 60,000 feet extending upward as high as balloon soundings have reached. These upper easterlies are the steadiest and most persistent winds known. Their steadiness exceeds that of the surface trades.

Temperature. The variation of surface air temperature at Eniwetok is extremely small -- a fact associated with its oceanic location and its latitude[4].

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[4]Length of the daylight period (sunrise to sunset) at Eniwetok ranges from 12 hours, 46 minutes to 11 hours, 29 minutes. Energy received at the outer atmosphere ranges from about 890 to about 600 cal./cm.^{2}/day. (After Robert J. List, Smithsonian Meteorological Tables, 6th edition). For times of sunrise and sunset see Table 2.

There is more temperature difference between night and day than there is between January and July. The greatest temperature changes are observed during rain showers, as a result of evaporative cooling. Mean-maximum and mean-minimum temperatures by month are given for Eniwetok in Table I.

Cloudiness. The dry season is normally considered to extend from mid-November through March and during this time total sky cover averages about 5 tenths. There is little if any observable diurnal variation in cloud amount. The dominant cloud form during this season is the typical trade wind cumulus with bases at about 1,800 feet and tops extending to the 4,000-5,000-foot level. Some middle cloudiness and cirrus may be observed in association with disturbed conditions in the more active convective areas located further south. As the season advances from April to late August or early September the cumuli typically present increase in vertical development so that by late summer cloud tops are normally found at the 8,000-9,000-foot level. At the same time, the amount of sky cover increases to an average of 6 or 7 tenths, due in part to more active cumulus development and in part to the more frequent appearance of

middle cloud and cirrus. Average cloud amounts at Eniwetok are given in Table I.

Precipitation and Tropical Storms. During the dry season, precipitation is almost entirely the result of cumulus-produced showers. These showers are normally of short duration, but through their frequent occurrence may produce several inches of rainfall in a month. During the summer and early autumn months, periodic disturbances in the trade wind current, which are known as easterly waves, move across the Eniwetok area and produce greatly increased cloudiness and precipitation. These wavelike deformations of the general easterly flow are first observed in the trade wind current in the vicinity of 140° W longitude. They move westward and slowly deepen until in some cases cutoff cyclonic disturbances are produced. These cyclonic vortices or tropical storms continue their westerly movement in the basic current and under certain special circumstances may develop into typhoons. It is uncommon, however, for typhoons to become fully developed in the Eniwetok area; perhaps one every five years is typical. With the passage of an easterly wave over, or to the south of, Eniwetok a general increase in cloudiness at all levels is observed together with numerous moderate to heavy showers and in some cases with light to moderate continuous rainfall. As the wave passes on westward the cloud conditions slowly return (after a day or two) to a typical trade wind cumulus distribution and precipitation is again produced almost exclusively by individual cumulus activity. The intensity and frequency of easterly wave formation reaches its maximum in late summer or early autumn, and a corresponding maximum in precipitation values is observed at that time. Mean precipitation amounts by months for Eniwetok are given in Table I.

4. HYDROGRAPHY

The four aspects of the hydrography of Eniwetok Atoll that are pertinent to the interpretation of the observations presented in this study are the bathymetry of the lagoon and immediately surrounding ocean waters, tidal variations, current systems in the lagoon, and mean water temperature relationships with special reference to seasonal variations in surface water temperature and changes in vertical temperature structure within the lagoon. Each of these topics is considered below.

On the broadest scale, Eniwetok consists of a reef and superincumbent islets

that enclose a large deep lagoon and that on the ocean side descend very steeply along the reef front into water that is hundreds of fathoms deep (Figure 3). The lagoon is generally deepest in its north central part, most of which lies below 32 fathoms, and it includes about 2300 coral knolls that rise to within a few fathoms of mean sea (lagoon) level as well as a 10-fathom terrace that borders the reef "along the east, north, and northwest side of the lagoon." Emery describes this terrace as follows:

> "The terrace is widest where the reef bends outward away from the lagoon and narrowest where the reef is indented toward the lagoon . . . . . . In the northwest part of the lagoon, where the terrace is widest it contains a depression which extends about 8 fathoms below the terrace surface . . . . ."[5]

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[5]K. O. Emery, "Submarine Geology of Bikini Atoll", Bull. GSA, LIX, 9, 855-59, 1948.

From the bathymetric chart that appears in Emery's article, it can be seen that this terrace is 1,000 to 5,000 feet wide. This same chart gives the bathymetric details for the entire lagoon floor. A more generalized chart of the floor appears in Figure 2; while Figure 1 shows sample soundings between ELMER and MACK and between BRUCE and KEITH, along the two lines that were followed in sampling lagoon water temperatures.

The mean tidal range at Eniwetok Atoll is 2.7 feet; the mean diurnal range, 3.9 feet. During the two periods of synoptic observation, in August, 1957, and in January-February, 1958, the high and low tides were as shown in Table 2, Appendix I.

The general pattern of current systems within the Eniwetok lagoon shifts continually with tidal variations and with changes in the speed and direction of the wind. However, some generalizations are warranted. With northeast to southeast winds, the surface currents probably form general patterns similar to those that have been observed at Bikini (Figure 5).

So far as surface water temperatures are concerned, the annual range over the nearby ocean is from a mean of 82° F. in late winter (February-March) to a mean of 83.5° in late summer (August-September) as shown in Figure 6. Vertical

temperature structure within the first few fathoms of water is closely related to windspeed. With winds in excess of 10-15 knots there is vigorous mixing and the structure is isothermal. Otherwise, the temperature tends to be isothermal at night (with surface cooling) and to increase upward only very slightly by day, with the temperature difference between the surface and the 2-fathom depth being a small fraction of a degree Fahrenheit.

5. TOPOGRAPHY[6]

As indicated in the introduction, weather observations during the Eniwetok Microclimatic Project were made at seven different sites in the atoll. These sites were on the islets of FRED, ELMER, BRUCE, YVONNE, JANET, KEITH and also in the lagoon at MACK (Figure 1). It is the purpose of this section to describe the local topography of each of these observation points.

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[6]Most of the detailed reef descriptions given in this section were obtained from "Geology of Bikini and Nearby Atolls" by Emery, Tracy, Ladd et al, USGS Prof. Paper No. 260-A, Part I, 1954. The reader is referred to this publication for more detailed information.

FRED, one of the principal islets of the atoll, is located at its southernmost extremity, immediately adjacent to the east side of Wide Passage. This crescent-shaped islet is oriented approximately northeast-southwest and measures some 2.6 miles long by 0.4 miles wide. The islet comprises some 0.8 square miles of dry land. The development of FRED as the principal permanent operational base has removed essentially all of its natural topographic features. It now consists of an essentially flat, graded, table some 11 feet above mean sea level. Only in the extreme northeastern portion of the islet are remnants of original relief still observed. An aircraft runway, numerous taxiways, aircraft parking areas and buildings occupy more than 90% of the western two-thirds of the islet. The eastern one-third of the islet is principally used for housing facilities for personnel. (See Figure 7.)

The seaward reef along the southeastern face of the islet is composed of four principal parts: (1) An Algal Ridge made up of small moderately well developed buttresses with small relatively straight and regular surge channels.

The ridge is approximately 50 feet wide and appears to be dead as a result of wartime damage and numerous fuel oil immersions. (2) The Outer Reef Flat is covered by 3 inches to 1 foot of water at low tide and consists of a flat of algal limestone covered with a soft velvety algal veneer and pitted with small depressions from a few inches to a foot or more in diameter. The outer reef flat is about 130 feet wide. (3) The Inner Reef Flat is exposed at low tide, rising gradually to about a foot above water level, and is covered over on its shoreward end with loose scattered cobbles. In some areas large blocks of the outer reef have been torn loose and lifted up onto the inner flat by the action of severe storms. (4) A Boulder Rampart makes up the very steep beach of cobbles. This feature is probably in large part artificial as a result of construction work on the islet, but the islet outline appears to have been changed very little. The lagoon beach which stretches along the northwestern face of FRED is a gently sloping scalloped beach made up largely of gravel and loose sand. In some areas, however, exposed rock is evident.

The original vegetation of FRED Islet has been almost completely destroyed as a result of the combined action of wartime assault and the postwar development of the islet. Only a few (six or seven) widely scattered mature cocopalms remain along the lagoon side of the western half of the islet. Additionally some scattered clumps of native *Scaevola* and of *Messerschmidia* remain in the easternmost end of the islet. In recent years some artificial planting has been accomplished, but at the present time these plantings do not appreciably alter the appearance of an almost completely barren islet.

ELMER, which is a principal islet of the atoll, is situated on its southeastern edge some 4 miles northwest of FRED and immediately adjacent to the southwestern edge of the Deep Entrance. This oblong islet is approximately 1.4 miles long and 0.3 miles wide; it consists of about 0.3 square miles of dry land. As in the case of FRED, the development of extensive permanent base facilities on ELMER has largely removed all traces of its former natural topography. It now consists of an essentially flat table some 11 feet above sea level. Housing facilities, technical installations and uncovered material storage areas cover more than 80% of this islet. (*See* Figure 8.)

The seaward reef and lagoon beach characteristics of ELMER are similar in almost all respects to those described in the case of FRED. An exception is the

large well developed rock flat which appears at the northernmost end of ELMER and forms the inner beach-face in that locality.

BRUCE, a smaller islet, is located at the extreme eastern edge of Eniwetok Atoll, about 5 miles north-northeast of ELMER. This islet has two principal parts: the larger part, roughly square in shape, comprises the entire northern end of the islet; the smaller part, an irregular narrow strip separated from the main islet by a water-filled depression in the reef, is situated at the southern end. BRUCE is approximately 0.4 miles long by 0.2 miles wide and contains less than 0.1 square statute miles of dry land. The erection of several measuring installations has not to any great extent affected the natural topography of the islet. As will be seen from Figure 9, the islet consists of an essentially flat table-land which occupies the entire central portion of the islet and is about 12 feet above sea level. Along the lagoon side of this table, which slopes gently downward from its seaward edge toward the lagoon, are several small dune-like mounds which reach elevations of 13 to 15 feet. Most of the observations taken on BRUCE, including the traverse observations, were obtained in the vicinity of an abandoned steel-mat airstrip which runs across the central part of the islet as shown in Figure 9. This airstrip has been abandoned for five or six years and is now covered with a growth of grass and weeds but as yet has not been over-grown by heavier brush.

The sea reef comprising the eastern edge of BRUCE is characterised by the extensive development of lines of groins or rock bars, transverse to the reef edge. The reef itself may be divided into five zones: (1) The Algal Ridge which slopes gently seaward with no buttresses apparent. This zone is approximately 80 feet wide with numerous surge channels in the form of widely spaced cracks 1 to 4 feet wide and 1 to 5 feet deep that extend 50 feet or more beyond the ridge crest. The channel walls are straight-sided and smooth; the floor is eroded algal limestone, its surface wavy and bare except for sparse gravel and boulder nodules in shallow potholes. The crest of the ridge is gently rounded and lies a foot or more above low water. (2) The Algal Pavement consists of a flat pavement of Porolithon, mostly yellow and dying, under one foot or more of water. The pavement is about 66 feet wide. (3) The Reef Flat is of orange-yellow algal limestone veneered by a thin film of Foraminiferal sand and marine algae. The flat surface is barren and covered with 2 to 6 inches of water.

It is steep on the seaward side and gently sloping on the shore side. Corals are rare or entirely absent except in small pools. (4) The Rock Bar or Groin, which is about 1300 feet wide, is a lithified conglomerate, modified by erosion and solution to form a rough platform about 3 inches above low water level. To landward the base of the bar is lithified and on it is piled a mass of loose boulders of coral and algal limestone. Further shoreward the rubble grows finer and the last 500 feet of the groin is a gravel and sand bar. (5) A narrow channel separates the groin from the islet beach and is gravel covered. The water here is one to one and one half feet deep at low tide and during early flood tide. The maximum current through this channel reaches 2 knots. The lagoonward side of BRUCE is composed of a number of scalloped gravel and sand beaches which slope gently out to a wide partially submerged rock flat.

BRUCE is covered almost completely with native vegetation. A more complete description of the vegetation is given in Section 6.

YVONNE, a medium-sized islet, is located along the northeast face of Eniwetok Atoll about 6 miles north-northwest of BRUCE. It is an elongated single islet measuring about 1.7 miles long and about 0.2 miles wide. Its dry land area comprises about 0.3 square miles (Figure 10). For many years this islet has been used as a shot site. As a result considerable modification of its natural topography has been produced. It is today a low-lying sand-covered flat with numerous deep and large depressions extending down into the reef structure below and with numerous dune-like hummocks which reach heights of 15 to 20 feet above sea level. The seaward and lagoon reef and beach characteristics are similar to those described in the case of BRUCE. As a result of numerous nuclear detonations, the islet is entirely devoid of vegetation.

JANET is a principal islet of the atoll and is situated at its northernmost extremity. It lies some 11 miles northwest of YVONNE and is roughly triangular in shape. JANET measures some 1.1 miles in a northwest-southeast direction and some 0.7 miles in a northeast-southwest direction. It contains about 0.6 square miles of dry land (Figure 10). This islet has also been used during previous years as a shot site and as a result is largely devoid of vegetation and has an appreciably altered topography. The islet consists of an essentially pyramidal table at some 15 feet above sea level with numerous large pits and depressions located along its seaward sides.

The seaward reef off JANET is comprised of four principal zones: (1) The Algal Ridge, which consists of a zone of buttresses and surge channels comparable in general form to those described for BRUCE. The ridge as a whole is dark brown with a few pink or light brown areas, but the darker parts of the ridge are almost black. Surge channels and pothole-like depressions are floored with sand and well-rounded coral pebbles and boulders. The ridge zone is about 60 feet wide. (2) The Coral Zone is a rough rock flat with a relief of one foot or more and a width of about 140 feet. Living corals are very numerous near the ends of the surge channels but over the zone as a whole they probably do not cover more than 15% of the surface. Near the landward edge of the zone are scattered remnants of an older algal limestone that rises from six inches to a foot above low tide level. (3) The Rock Flat, which is about 910 feet wide, is a barren surface with many pools in pits and irregular depressions. The surface is rough near its seaward edge becoming smoother lagoonward with thin patches of sand. (4) The Beach Zone is covered with a fine ripple-marked sand at the edge of the rock flat. At higher levels the covering becomes coarser with worn coral heads commonly exceeding a foot in diameter. The lagoon beach at JANET is a broad gravel and sand beach sloping gently lagoonward and extending out into relatively deep water.

KEITH, a minor islet of the atoll, is located on its southwestern edge about 12 miles almost due west of FRED Islet and some 2-3 miles southeastward from Southwest Passage. KEITH is nearly teardrop shaped and measures about 0.3 miles long by 0.1 miles wide. It is oriented approximately northwest by southeast and consists of less than 0.1 square miles of dry land. No large installations have been placed on this islet and as a result both its natural topography and vegetation have remained largely undisturbed. A relatively narrow ridge, lying along the central axis of the islet and reaching heights above 13 feet above sea level, is the most prominent feature on this islet. The land slopes gently both lagoonward and seaward from this narrow ridge (Figure 11). As one proceeds along the ridge in a southeasterly direction it terminates near the center of the islet, where the land surface slopes steeply down to a nearly flat table-like area located about 5 feet above sea level. This table area comprises the entire southeastern half of the islet.

The seaward reef along the southwestern edge of KEITH can be divided into

four principal zones. (1) The Terrace slopes seaward for some 100 to 300 feet, where at an apparent depth of 10 or 15 fathoms it drops off quite steeply. At its outer edge it consists of irregular lobate algal spurs, separated by wide deep canyon-like channels which extend far down below sea level. These are about 30 feet deep at the reef edge and continue seaward to the edge of the terrace. (2) The Algal Ridge does not rise to a well defined crest; instead there are scattered hummocks or mounds about 20 to 60 feet across that rise to a maximum of 1 foot above low tide level. The zone is about 200 feet wide. (3) The Reef Flat, which at low tide is covered with about 1 foot of water, is a floor of algal limestone, irregular and hummocky with sandy patches in the hollows. This zone is about 50 feet wide. (4) The Beach Rock Zone, which is about 30 feet wide, consists of a rough rock platform on which lie boulders and the bedded sandstone of the islet shore. The lagoon beach side of KEITH is composed of a sharply sloping and narrow sand beach which extends down to about low water level and there meets a flat of coral limestone which gradually slopes downward as one proceeds toward deeper lagoon water.

Heavy vegetation on KEITH is located principally on its northwestern half. A heavy stand of mature coconut trees dominates this area. The southeastern half of the islet supports only secondary brush-type vegetation, principally *Scaevola*. (*See* Section 6.)

MACK is an artificial site built upon a very large coral head which is located in the northeastern quadrant of the lagoon. MACK is approximately 7 miles due west of YVONNE and 8 miles due south of JANET. This site consists of a large platform some 10 feet above sea level upon which has been built a steel tower some 85 feet in height (Figure 12). There are no exposed land areas at this site.

6. VEGETATION

Eniwetok Atoll is considered on the basis of the vegetation to be one of the drier of the Marshall Islands. This is evidenced by the lack of ferns such as *Polypodium* and *Asplenium*, and of shrubs such as *Pipturus*, which are present on many of the other atolls. The paucity of bryophytes and foliose lichens above a meter or a meter and a half above the ground is further indication of the comparative dryness.

Even so, the atoll received sufficient moisture to maintain vegetation on almost all portions which are continuously above high tide. The character of this vegetation is a result of human activity and the bio-physical factors such as soil and underlying rock, waterlevel, and tolerances of individual species. It has not been possible to make a careful study of all of these factors. However, observations and suggested correlations may be of some value.

As would be expected on a group of small islets composed almost exclusively of coral and coralline sand with many fragments of mollusc shells, the vegetation is a strand vegetation with Scaevola frutescens and Messerschmidia argentea the most frequent shrubs or small trees. Where the soil is somewhat richer in organic matter Pisonia grandis, Guettarda speciosa and, on some islets, Cordia subcordata become more frequent. Coconuts occur in regular rows, having been planted by the Japanese or Marshallese Islanders. Beneath the trees, which may reach 60-70 feet in height, there are hundreds of sprouted nuts as well as seedlings and small plants of the more common shrubs and plants. Vines are an important adjunct to the vegetation along the margins of the tall shrub thickets or forest.

Broadly speaking, the vegetation may be described as composed of three relatively distinct "zones". The first of these is low, with the plants and shrubs not, or barely exceeding, one meter in height. The factor which seems to determine the presence of this type of vegetation is shallow sand or isolated sand spits separated from the main water lens of the islet. It is here that Triumfetta procumbens and Ipomoea pes-caprae, both trailing or creeping vines, reach their maximum development. Low, stunted or dwarfed Scaevola also occurs with patches of Lepturus forming open grass-mats on the higher or deeper-sandy spots.

The "tall shrub" type of vegetation, consisting of shrubs to five or six meters tall, occupies the major part of each islet. Scaevola frutescens and Messerschmidia argentea compose the greater portion of this shrub. Ipomoea tuba is generally found at the "contact" of this vegetation with the low strand vegetation. Somewhat richer soils support Guettarda speciosa, Cordia subcordata, and Terminalia littoralis.

Rocky-sandy spits, even though separated from the main water-lens, are occupied by this type of vegetation, but with Pemphis acidula as the nearly

exclusive member. The individuals form a "scrub" or "chaparral" with open bare substrate between them.

The "forest", if this designation may be used, is restricted to those areas of the islets where the depth of the soil or rock substrate is such that a distinct "water-lens" only of brackish water is formed. Pisonia grandis is the major species, although Ochrosia oppositifolia and Cordia subcordata may, formerly, have reached their maximum development in this type of vegetation.

The coconut plantations were planted in the forest area where they were underlain by soil and in the high shrub type of vegetation.

Since there were two areas intensively studied, one on the windward, and one on the leeward, side of the atoll, it may be useful to describe and discuss these areas separately. These descriptions should be read in conjunction with Figures 13 and 14.

KEITH. Underlying the entire islet appears to be a shelf of consolidated coral sand and shell rock which has its upper surface at about the high tide level. This shelf rock is soft and easily broken and begins on the ocean side approximately at the beach. On the lagoon side it extends 100-200 feet lagoonward of the high tide line.

The southeast half of the islet forms a shallow basin about 1-2 feet above high tide level, enclosed by a sandy ridge 3-8 feet above the floor of the basin. Within the basin the high scrub in the chaparral are generally only 1-2 meters high, though occasional larger shrubs occur. The individuals are generally 5-10 meters apart and numerous seedlings are present. Messerschmidia and Scaevola are the only shrubby species found. They are subglobose in shape, with the lateral branches touching the ground. Between the shrubs may be found clumps of Tricholaena repens and Fimbristylis atollensis. The rim on the lagoon side carries the low vegetation with a preponderance of Scaevola, Triumfetta and Lepturus. On the lagoon side of the rim are distinct rows of Messerschmidia seedlings corresponding to windrows of seaweed (a greater portion of which is Turbinaria) washed up by the sea and the Trades.

The rim on the ocean side is covered by the high shrub Messerschmidia and Scaevola. Triumfetta and I. tuba occur as scattered plants and Lepturus is almost entirely absent. The beach slope is nearly bare, with only scattered clumps of Triumfetta.

The northwest side of the basin area rises rapidly to the high portion of the islet. Guettarda enters the composition of the shrub here, and is found in reduced numbers throughout the rest of the islet. The ocean side of the islet is underlain by broken rock of irregular sizes, filled between with sand. This area was not planted to coconuts and here the Pisonia reaches its maximum development in an open forest, with Boerhaavia forming the major part of the ground cover. The lagoon half of the high part of the islet is covered with deeper soil and coconuts have been planted. The high shrub forms a definite understory, but Terminalia is found only along the lagoon-side margins. In disturbed soils of this area the ephemeral weeds Portulaca oleracea and Fleurya ruderalis may be found. Pemphis acidula and Suriana maritima occur as isolated individuals on the high shrub margins of the high portion of the islet.

BRUCE. The islet of BRUCE is apparently underlain by a coral sand rock which has been mainly broken up into irregularly sized rocks under the islet itself, but is mainly unbroken in the shallow waters surrounding the islet.

The southeast portion of the islet is a long sand spit with a short perpendicular spit extending oceanward. The long spit is covered by the low vegetation with extensive open patches of Lepturus. Along the highest portion the Messerschmidia and Scaevola take on the character of the high shrub. The perpendicular spit which is covered by high tides has the high shrub Pemphis.

The main part of the islet is covered by the high shrub, and except for a band on the ocean side 10-20 meters broad had been entirely planted to coconuts. This band is underlain by the broken coral-sand rock with little soil or sand between. The Scaevola is the dominant shrub in this region with almost no ground cover and no vines. In back of this band the Messerschmidia becomes dominant. Here too, vines and ground cover is lacking. On the lagoon side of the islet there is apparently a greater accumulation of organic matter in the soil. Pisonia and Cordia nearly exclude the other shrubs. I. tuba forms a nearly continuous blanket on the margin.

An airstrip that had been cut out of the vegetation just southeast of the center and a road connecting the strip with the landing on the lagoon side near the northwest end form openings in this vegetation. The strip, which is no longer in use, and the road are covered or bordered by Fimbristylis in the open. In the shadier portions of these clearings the weedy grass Eragrostis and

Portulaca (P. oleracea and P. samoensis) form the ground cover. Boerhaavia is the principal ground cover under Pisonia and Cordia.

7. THE OBSERVATIONS

Four aspects of the observational program require consideration: the plan of observation, instrumentation, instrument exposure (including site details), and observational procedures. In addition to make the data collected in this study most useful it is necessary to estimate how reliable the different kinds of observations were. Except for the observational plan, all of these aspects of the observations are considered specifically in the detailed notes that accompany the Tables in Appendix I.

Plan of Observation: The intensive observational periods extended from 1200 August 18th through 1100, September 1st, 1957 and from 1200 January 25th through 1100, February 8th, 1958 (180th meridian time). The plan of observation is summarized in Table II. This plan was, in fact, followed reasonably closely with three principal exceptions: because of various difficulties that will not be described, there were days on which cloud photographs were not obtained and on which radarscope pictures were not obtained; and hygrothermograph records were not obtained for every day at all locations. In addition, a few of the 3-hourly observations were missed at KEITH and BRUCE, while at the northern islet sites (YVONNE and JANET) a few daily rainfall observations were missed. The tabular data in Appendix I show precisely what these various omissions were.

During the actual intensive observational periods, special traverses were made on BRUCE and KEITH to determine micro-scale variations in the dry- and wet-bulb temperatures and in the temperature of the ocean and lagoon water at shallow depths upon the reef. Despite their relative paucity, these supplemental observational data may prove of interest to some investigators.

The extensive observational phase covered two periods: from September 1, 1957 through January 24, 1958 and from February 9, 1958 through August 17, 1958. Throughout almost all of this period semi-monthly rainfall totals were obtained at BRUCE and KEITH and daily totals were obtained at FRED and ELMER. In addition, some additional rainfall readings were made on YVONNE, JANET, and MACK.

Organization of Observational Data: The bulk of the observational data are presented in the Tables of Appendix I, which contains its own Table of Contents,

TABLE II. OBSERVATIONAL PROGRAM DURING INTENSIVE OBSERVATIONAL PERIODS
(August 18 - September 1, 1957: January 25 - February 8, 1958)

Abbreviations:
O: Occasional
D: Daily
12: 12-hourly
3: 3-hourly
3D: 3-hourly, daylight hours only
2: 2-hourly
H: Hourly
C: Continuous recording

SITE OR ZONE	Air pressure	Dry bulb temperature	Wet bulb temperature	Surface wind	Rainfall	Maximum temperature	Minimum temperature	Sky Cover	Clouds	Ceiling	Humidity	Present Weather	Cloud photograph	Radarscope photograph	Rawinsonde	Surface water temperature
FRED (USAF)	H	H	H	H	D	D	D	H	H	H	-	H	-	3	12	-
ELMER	-	D	D	D	D	D	D	D	D	-	-	O	-	-	-	-
BRUCE	-	3	3	3	3	12	12	3	3D	-	C	O	3	-	-	-
KEITH	-	3	3	3	3	12	12	3	3D	-	C	O	3	-	-	-
MACK	-	D C	D	D	D	D	D	D	D	-	C	D	-	-	-	-
JANET	-	-	-	-	D	-	-	-	-	-	-	-	-	-	-	-
YVONNE*	-	-	-	-	D	-	-	-	-	-	-	-	-	-	-	-
LAGOON	-	D	D	-	-	-	-	O	O	-	-	O	-	-	-	D
OCEAN	-	O	O	-	-	-	-	O	O	-	-	O	-	-	-	O
MSTS SHIP**	2	2	2	2	-	-	-	2	2	-	-	2	O	O	-	O

* Second intensive period only.

** First intensive period only.

List of Abbreviations, Code Names and Symbols, and Notes. In using the data appearing in Appendix I reference should be made to the General Notes at the beginning of the Appendix as well as to the detailed, specific notes for the individual tables that are being used. Appendix II provides two Indices, one to the Radarscope Pictures; the other, to the Cloud Pictures. This Appendix also contains specific notes and states how copies of these pictures can be obtained on loan. Supplemental data sources are listed in Appendix III. All Figures and Plates referred to in the Appendices, as well as in the text, appear at the back of this publication and are listed on page ix.

APPENDIX I

APPENDIX I.

TABULAR PRESENTATION OF OBSERVATIONAL DATA

N.B. It is recommended that the data in this Appendix be used in conjunction with the corresponding Notes. These Notes describe the observational sites and procedures, specify the instruments used, and provide estimates of the extreme limits of accuracy of the observations. The accuracy limits given can be applied to estimate the significance of comparative observations as well as of any particular observation. In this connection it is noted that even in instances in which the extreme limits of accuracy exceed the difference between two observations, the difference may have some significance. Significance is related to the nature of the statistical populations from which the observations are drawn, a subject discussed in some detail in the references cited in Appendix III.

CONTENTS OF APPENDIX I.

Part D. Observational Data for Extensive Phase

(September, 1957 -- August, 1958)

APPENDIX I.

GENERAL NOTES

N. B. These General Notes should be consulted before utilizing any of the observational data of this Appendix. The General Notes describe the observational sites and instrument exposures on the various islets and at MACK, state the types of instruments used, and give the procedures used in making shipboard observations. Thus these Notes supplement the far broader descriptions of the various islets given in the text. The Specific Notes for the individual tables, as listed in the Table of Contents, Appendix I (preceding pages), should also be consulted before utilizing the data. The Specific Notes describe departures from general observational practices as stated in the General Notes, give estimates of the reliability of the observations, and provide specific comments that will be useful in interpreting the observational data.

Observation Sites, Instrumentation, and Instrument Exposures at Land Stations and at MACK

FRED

Site Description: Figure 7 shows the location of buildings and of instruments on FRED. The shelter, raingages, special anemometer, and the tower on which the regular anemometer was located were all surrounded by barren ground composed of coral sand and gravel. The tower, however, was immediately adjacent to a surfaced taxi-way that was an apron of the main runway.

Instruments:

(a) Raingages: Standard 8-inch raingages were used at both locations 1 and 2. Raingage 2 was located about 15 yards SW of a 2-story building and it was this gage that was used for regular observations at the USAF weather station up until February 1, 1958. The gage appeared to be in too sheltered a location with reference to the tradewinds; and for this reason gage 1 was established at a distance of about 60 yards from the building. On February 1 this new location was adopted as the location of the official gage, and effective that date there were rainfall readings only from this one point.

(b) The shelter was of the standard Cotton Region type, with the door facing NNW.

(c) The direct reading dry-bulb thermometer was a mercury-in-glass instrument of the standard tropical type (USAF tropical thermometer). It was graduated in half-degrees Fahrenheit.

(d) The wet-bulb thermometer was a jacketed variety of the dry-bulb, mounted in the shelter on a standard hand-crank apparatus.

(e) Both anemometers were standard 3-cup instruments. Anemometer #1 was an instrument that showed total nautical miles of wind on a dial that was read directly. This anemometer was mounted on a special mast at a height of 11 feet above the ground (18-20 feet above mean sea level). Anemometer #2 was a recording (triple-register) instrument mounted on the tower at a height of 33 feet above the ground (41-43 feet above mean sea level).

(f) Barometry was based on a standard mercury instrument that was used to check daily the recording microbarograph from which the observational values were obtained. Values are given here in terms of station pressure, which represents a height of 19 feet above mean sea level.

(g) A GMD-1a was used for rawinsonde observations.

(h) The radarscope was a CPS/9.

BRUCE

Site Description: Figures 9 and 14 show the location of instruments on BRUCE and Plate I shows views of these instruments. These figures and the photographs in the Plate give detailed information as to the nature and distribution of ground cover and as to the topography (very minor relief) of the Islet. The ground was predominantly barren beneath the anemometer, the shelter, and the raingages and consisted of beach-rock covered by a veneer of coralline sand and gravel.

Instruments:

(a) Raingages: Standard 8-inch gages were used at both the Ocean and Lagoon sites.

(b) The shelter was of the standard Cotton Region type, with the door facing north.

(c) The anemometer was a 3-cup instrument with a totalizing dial (values given in nautical miles). It was mounted on a special mast at a height of 11 feet above the ground (18-20 feet above mean sea level).

(d) Maximum and minimum thermometers were mounted in the shelter in the standard manner (on the cross-beam, just forward of the back of the shelter, facing the door). These were standard Weather Bureau instruments: mercury-in-glass and alcohol-in-glass.

(e) A standard hygrothermograph was kept in the shelter. This was a Friez recording instrument, with a 7-day setting (7-day chart), and with a hair-and-lever mechanism for recording relative humidity.

(f) Direct dry-bulb and wet-bulb temperature readings were made using a Friez psychron (mercury-in-glass thermometers graduated in whole-degrees Fahrenheit and mounted in a unit with a battery-driven fan). The psychron was placed in the shelter and the reading was made at the time of lowest wet-bulb reading.

KEITH

Site Description: Figures 11 and 13 show the location of instruments on KEITH and Plate II shows views of these instruments. These figures and the photographs in the Plate give detailed information as to the nature and distribution of ground cover and as to topography. The ground was barren beneath the shelter, anemometer, and raingage, and consisted of beach-rock covered by a thin veneer of coralline sand and gravel.

Instruments:

The instruments used were identical with those for BRUCE (above). Figures 11 and 13 and Plate II provide information concerning instrument exposure.

ELMER

Site Description: Observations were made at two different sites. Through February 28, 1958, observations were made near the northeastern end of ELMER, with the raingage and the shelter in a large open area lying between a tank farm (to the NE) and quonset huts (to the SW). Effective March 1st, rainfall observations were taken near the dispatchers shack at the airstrip toward the SW side of ELMER. At both sites, the instruments were well out in the open and were underlain by barren ground consisting of coralline sand and gravel. Shelter and raingage locations with reference to buildings are shown in Figure 8.

Instruments:

(a) The shelter was mounted on a post at a medial height of $5\frac{1}{2}$ feet. It was 2X2X1 ft. with the 1 ft. length applying to the depth. The door, which faced NE, was full and hinged to swing upward. The shelter was made of light wood except for the

back, which was masonite. The door was fully louvred, but the other five interior faces were solid.

(b) The maximum and minimum thermometer was of the U-type (mercury-in-glass) with a magnet for re-setting the rider. It was graduated in whole-degrees Fahrenheit. The thermometer was mounted on an upright post in the shelter.

(c) The raingage was a standard 8-inch one.

(d) Direct dry-bulb and wet-bulb readings were taken using a Friez psychron (mercury-in-glass thermometers graduated in whole-degrees Fahrenheit and mounted in a unit with a battery-driven fan). Psychron readings were made outside the shelter, in the shade, at a 5-foot height with the observer standing to leeward of the psychron.

(e) A standard recording hygrothermograph was maintained in the shelter (see description of this instrument under BRUCE instrumentation, above).

MACK

Site Description: This tower site is diagrammed in Figure 12. The raingage and shelter, whose location is also shown in this figure, were located on a side platform immediately to the south of the tower and at a height of $17\frac{1}{2}$ feet above mean low lagoon water.

Instruments:

(a) The standard, 8-inch raingage was at the extreme SE edge of the platform. Because it was only four feet south of the standard shelter, the catch was probably biased due to eddies, especially when rainfall occurred with a north wind.

(b) The instrument shelter was of the standard Cotton Region type with the door on the west side.

(c) Maximum and minimum thermometers, the hygrothermograph, and the psychron for direct reading of dry-bulb and wet-bulb temperatures were of the same kinds that were used at KEITH and BRUCE (see above).

JANET AND YVONNE

Only standard 8-inch raingages were installed on these islets. In both instances they were placed on level terrain comprised of coralline sand and gravel with beach-rock beneath. Both were well exposed, with no obstruction of any kind within 100 yards. Their locations are shown in Figure 10.

Shipboard Observations

LAGOON TRAVERSES

Lagoon traverses were made on M-boats (LCMs). Water temperatures were measured through making hauls in a canvas bucket, the hauls being made on the windward side of the boat, 1-3 yards to the stern of mid-ship, well forward from the exhaust. Upon completing the haul, the bucket was placed in the shade of the steering-house and a thermometer was placed in the water with its bulb at a depth of 6-10 inches and held there until the mercury reached its lowest point. Except where otherwise noted in the Specific Table Notes that follow, the thermometer that was used was a special water thermometer, graduated in tenths of a degree Fahrenheit and mounted on a wooden backing with a perforated brass shield surrounding the thermometer bulb at a distance from the bulb of about 2/3 inch. Thus the bulb was shielded from the sun but was fully exposed to the water. Dry-bulb and wet-bulb air temperatures were obtained from the deck of the boat on the windward side well forward of the exhaust with the instrument shielded from the direct rays of the sun. Except where otherwise noted, observations were made with a psychron (see instrument description under BRUCE, above); and whether or not a psychron was used the observations were made at a height of about 5 feet above the deck or a total height of about 11 feet above the water.

OCEAN TRAVERSES

Ocean traverses were made on a crash-boat (AVP), with the observations being made forward, almost to the bow. As in the case of the lagoon observations (see above), water temperatures were obtained through bucket hauls and air temperatures (dry-bulb and wet-bulb) were obtained using a psychron. Air temperatures were taken at a height of about 5 feet above the forward (cockpit) deck, or about 7 feet above the water.

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Air temperature observations were from instruments in a louvred shelter on the port bridge wing, at a height of about 30 feet above the water. Thermometers were probably alcohol-in-glass, though this cannot be checked absolutely. Air pressure was from a Taylor aneroid located in the chart room. It was temperature-compensated in 1954 and corrections during 1954-1958 (inclusive) have not exceeded 0.05 inch. Water temperatures were standard intake temperatures.

NOTES: TABLES 1-3

TABLE 1. ABBREVIATIONS, CODE NAMES, AND SYMBOLS.

This Table is self-explanatory. With one exception it lists all abbreviations, code names, and symbols used in the text and in the Tables. The exception is the code names for locations other than OSCAR, REX, and SAM. The remaining code names used herein are shown in Figure 1.

TABLE 2. ENIWETOK ATOLL: HIGH AND LOW TIDES, SUNRISE AND SUNSET.

All times given are 180th meridian. Tidal heights are correct to 0.1 foot at the northwest end of FRED, on the lagoon side, where the tide gage is located. Heights vary only by a few inches from one to another islet, not including the effect of piling up of water by wind. From the observations of surveyers at Eniwetok (personal communication), it is judged that with moderate to strong tradewinds blowing there is an increase in tide height of from 1 to 2 feet along the east coasts of the islets, this increase being above that observed at the tide gage. This increase occurs on the lagoon side of the western islets as well as on the ocean side of the eastern islets.

As for currents in the lagoon, according to H. O. Pub. No. 165A, Sailing Directions for the Pacific Islands (1952), "In Deep Entrance a maximum flood current of 2 knots, setting westward, occurs 2 hours after low tide. A maximum ebb of 1¼ knots, setting southeastward, occurs 50 minutes after high tide. Slack water occurs 40 minutes before low tide, and 20 minutes after high tide. . . . . In Wide Passage a maximum flood current of 1 knot, setting westward; occurs 1h. 10m. after high tide. A maximum ebb of 0.7 knot, setting 210°, occurs 2h. 27m. before low tide. Slack water occurs 2h. 48m. after high tide, and 1h. 28m. before low tide."

Sunrise and sunset are defined in the standard manner the times being given as those "at which the upper edge of the Sun's disk is actually seen on a regular and unobstructed horizon, under normal atmospheric conditions, by an observer at zero elevation above the Earth's surface in a level region." (Introduction to Tables of Sunrise, Sunset, and Twilight, U. S. Naval Observatory, Washington, D. C.)

TABLE 3. FRED: NAUTICAL MILES OF WIND (NOON TO NOON, 180TH MERIDIAN).

The low level anemometer was at the same height as those on BRUCE and KEITH. During the first Intensive Phase of the study (August-September, 1957) these three anemometers were compared both before and after the 2-week observational period. Comparisons were made through mounting each anemometer on a 6-foot pole and placing these along the beach on ELMER, with the anemometers aligned up-beach one from the other at successive distances of about 10 feet. The anemometers were rotated as to position and the total values were compared. 5-6 hours was allotted for each comparative run. Results of the inter-calibrations, before and after the observational period, were as follows (in percent of wind totals):

BEFORE: FRED and KEITH anemometers agreed consistently within 4%, with the FRED anemometer consistently the higher.

BRUCE anemometer consistently the lowest of the three, with the values ranging from 25-33% of the mean of FRED and KEITH.

AFTER: FRED consistently higher than BRUCE by 1-2%.

KEITH consistently 2-15% lower than the mean of FRED and BRUCE.

After the second calibration run, it was discovered that a nut had fallen into the housing of the KEITH anemometer. When this occurred is not known.

During the second Intensive Phase (January-February, 1958) there was no low-level anemometer at FRED, since it was found that one of the three totalizing anemometers was broken and it was decided to retain the wind measurements on BRUCE and KEITH, rather than FRED. Circumstances did not permit making calibration runs prior to this second observational period, but runs made afterward showed that the BRUCE and KEITH anemometers agreed within 10%. It is not known which, if either, anemometer was consistently higher.

NOTE: This comparative table for FRED may permit an estimate of low-level wind conditions during the second Intensive Phase through reducing the wind readings at the FRED tower (high level) by a factor of 22%. It should be noted, however, that Table 3 shows a general tendency for closer agreement between the high and low anemometers when winds are higher than when winds are lower; and since winds were decidedly higher during January-February than during August-September, this reduction coefficient should probably be decreased somewhat.

ABBREVIATIONS, CODE NAMES, AND SYMBOLS

TABLE 1

(For further details see NOTES for individual tables.)

Ac	Altocumulus
As	Altostratus
b	Cloud height determined by balloon.
C	Calm
Cb	Cumulonimbus (thunderstorm) cloud
Cc	Cirrocumulus
C_H	High cloud
Ci	Cirrus
C_L	Low cloud
C_{LMH}	Clouds: low, middle, high
C_M	Middle cloud
Cs	Cirrostratus
Cu	Cumulus
DD	Wind direction (to points of the compass or in tens of degrees)
DDFF	Wind direction (to points of the compass or tens of degrees) and windspeed (in knots unless otherwise specified)
e	Cloud height estimated
FF_3	Mean windspeed in knots over three hours ending at observation time.
m	Cloud height measured (with ceiling light or ceilometer)
M	Observation missing because of technical difficulty.
MB	Motor-boating. Humidity too low to be measured accurately. (Estimated value given in parentheses.)
N	Total sky cover (in tenths)
N_8	Total sky cover (in eighths)
N_O	Total opaque sky cover (in tenths)
OSCAR	Name of lagoon tower SE of MACK. (see map)
P	Surface air pressure, at station height
REX	Very small islet 3/4 mile NNW of ELMER (on northern edge of deep entrance).
RH	Relative humidity (in percent)
RR	Rainfall amount since last observation or for period shown.
RR_L	Rainfall at gage on lagoon side of BRUCE.
RR_O	Rainfall at gage on ocean side of BRUCE.
SAM	A very small islet on the eastern reef 1-7/8 miles NNW of BRUCE.
Sand Island	Small sand islet between ELMER and FRED.
Sc	Stratocumulus
SEA (code)	State of Sea is given in code according to the following scale: 0 - Calm sea, less than 1 foot 1 - Smooth sea, 1-2 feet 2 - Slight sea, 2-3 feet, occasional small whitecaps 3 - Moderate sea, 3-5 feet, sustained whitecaps 4 - Rough sea, 5-8 feet, large waves, large sustained whitecaps
St	Stratus
T	Trace of rainfall (less than 0.01 inch)
TT	Dry bulb temperature (in Fahrenheit unless °C specified, when in centigrade)
T_dT_d	Dewpoint temperature
T_nT_n	Minimum temperature since time of last observation of minimum.
TT_s	Surface sea water temperature
TT_w	Wet bulb temperature
T_xT_x	Maximum temperature since time of last observation of maximum.
WX	Present weather
ϑ	Bearing in degrees
( )	Approximate value, or when used with cloud type indicates less than one-tenth.
?	Approximate value, or (for cloud type) identification uncertain.

PLACE: ENIWETOK ATOLL HIGH AND LOW TIDES, SUNRISE AND SUNSET TABLE 2

TIDES

DATE	TIME	HEIGHT* (ft.)	DATE	TIME	HEIGHT* (ft.)
8/18/57	0200	1.8	1/25/58	0054	0.6
	0753	3.4		0701	3.8
	1407	1.7		1257	1.6
	2041	3.5		1904	4.9
8/19/57	0307	2.1	1/26/58	0122	1.1
	0852	3.0		0734	3.6
	1509	1.9		1329	1.5
	2210	3.4		1934	3.6
8/20/57	0518	2.2	1/27/58	0152	1.4
	1101	2.8		0812	3.5
	1710	2.1		1411	1.8
				2009	3.3
8/21/57	0010	3.5	1/28/58	0239	1.6
	0714	1.9		0905	3.3
	1308	3.0		1512	2.1
	1858	1.8		2102	2.9
8/22/57	0131	3.9	1/29/58	0329	1.8
	0812	1.5		1035	3.1
	1410	3.4		1719	2.2
	2002	1.5		2300	2.8
8/23/57	0224	4.3	1/30/58	0518	2.0
	0856	1.1		1231	3.3
	1455	3.8		1924	1.9
	2051	1.1			
8/24/57	0309	4.7	1/31/58	0111	2.1
	0934	0.7		0700	1.8
	1534	4.2		1343	3.7
	2134	0.7		2022	1.5
8/25/57	0349	5.0	2/1/58	0217	3.2
	1010	0.5		0803	1.5
	1612	4.5		1433	4.1
	2215	0.5		2103	1.2
8/26/57	0428	5.2	2/2/58	0302	3.5
	1045	0.3		0850	1.2
	1648	4.8		1513	4.5
	2254	0.4		2140	0.8
8/27/57	0505	5.1	2/3/58	0340	3.8
	1120	0.3		0931	0.8
	1724	4.8		1551	4.8
	2332	0.4		2215	0.5
8/28/57	0542	4.9	2/4/58	0415	4.2
	1153	0.5		1011	0.5
	1800	4.7		1628	5.0
				2250	0.3
8/29/57	0010	0.6	2/5/58	0451	4.4
	0617	4.5		1049	0.4
	1227	0.8		1705	5.1
	1837	4.5		2323	0.2

PLACE: ENIWETOK ATOLL — HIGH AND LOW TIDES, SUNRISE AND SUNSET — TABLE 2 (Concluded)

TIDES

DATE	TIME	HEIGHT* (ft.)	DATE	TIME	HEIGHT* (ft.)
8/30/57	0050	0.9	2/6/58	0527	4.5
	0654	4.2		1127	0.4
	1300	1.1		1741	5.0
	1916	4.2		2357	0.3
8/31/57	0132	1.4	2/7/58	0603	4.5
	0730	3.7		1205	0.5
	1334	1.5		1818	4.8
	1958	3.8			
9/1/57	0223	1.8	2/8/58	0033	0.5
	0812	3.2		0640	4.4
	1414	1.8		1245	0.7
	2058	3.5		1855	4.4

SUN

DATES	SUNRISE**	SUNSET**
8/18 - 9/1/57	0700	1930 - 1920
1/25 - 2/8/58	0735	1910 - 1915

* Tide height above ½ ft. below mean low water springs for Kwajalein.
Source: U. S. Coast and Geodetic Survey, Tide Tables, Central and Western Pacific Ocean and Indian Ocean, 1958 (Wash. D. C., Gov't Prtg. Office).

** To nearest five minutes, 180th Meridian time.

PLACE: FRED — NAUTICAL MILES OF WIND (NOON TO NOON, 180th MERIDIAN) — TABLE 3

- COMPARATIVE VALUES -

DATE	ANEMOMETER #1 (On ground-based mast)	ANEMOMETER #2 (On tower)
18 - 19 August, 1957	92.2	176.0
19 - 20 August, 1957	217.5	283.0
20 - 21 August, 1957	235.4	254.0
21 - 22 August, 1957	181.9	218.0
22 - 23 August, 1957	180.5	259.0
23 - 24 August, 1957	288.5	262.0
24 - 25 August, 1957	131.8	219.0
25 - 26 August, 1957	51.0	110.0
26 - 27 August, 1957	187.5	212.0
27 - 28 August, 1957	208.5	218.0
28 - 29 August, 1957	154.0	210.0
29 - 30 August, 1957	143.1	251.0
30 August - 1 September, 1957*	417.7	526.0
	2489.6	3198.0

*To 0900, 1 September.

Part B. Observational Data, First Intensive Phase (August 18 -- September 1, 1957)

NOTES: TABLES 4-18

TABLE 4. FRED: HOURLY OBSERVATIONS AND DAILY SUMMARY.

These Notes apply both to Table 4 and Table 19, which presents similar observational data for the second Intensive Phase.

P represents station pressure and is given to thousandths of an inch, with the units and tens omitted. In Tables 4 and 19, all values are preceded by 29, except 000, which represents 30.000. The mercurial barometer (used daily to check the microbarograph) was calibrated January 30, 1958 and found to be 0.020 inch too low. This value should be added to those shown in the Tables. In addition, unreliability is introduced because the hourly values were read from the microbarograph and because of the lag in this instrument. Allowing for this factor, after 0.020 has been added to the values, the resulting values will all be correct within 0.020 (plus or minus) and half of the resulting values will be correct within 0.004.[1]

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[1]The extreme error of 0.020 represents the maximum 10-minute change that may be expected at Eniwetok, considering both the diurnal pressure curve and the changing synoptic situations. (More rapid change might accompany approach of a typhoon or an intense tropical storm, but such did not occur during these observational periods.) The ten minute period represents the maximum time-lag between the mercurial barometer and the microbarograph at times when the pressure is changing rapidly. (When it is changing very slowly the lag may be greater, but then the error amplitude is diminished very appreciably.) The value 0.004 is based on the assumption that rates of change of pressure over 5-10 minute periods are distributed normally about their mean. Finally, it should be noted that these error estimates allow for the fact that often in actual practice observers do not tap the microbarograph to permit the pen to adjust to the current pressure.

TT and TT_W were to be read to 0.1° F. according to standard instructions. It is evident, however, from the very high frequency of values ending in .0 or .5 that the observers usually read the temperature to the nearest graduated mark (.0 or .5). Allowing for this fact and for an extreme instrumental error of 0.3°, all values are correct within 0.5°.[2]

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[2]This assumes there is no consistent bias, either instrumental or human, and that in borderline cases the observer can discriminate to 0.1°.

RH is a calculated value based on TT and TT_w. (P is an insignificant factor for our purposes.) It follows that for the dry-bulb and wet-bulb temperatures experienced at Eniwetok all RH values are correct within 6%, and 9 out of 10 are correct within 4% (assuming normal error distribution and allowing for 1% error in conversion).

N is probably too high, especially at night, in all instances in which it largely depends on an observation of 10 Cs. An exception would be when 10 Cs was also observed at one of the other stations (BRUCE, KEITH, ELMER or MACK). It is noted that 10Cs was seldom reported at these other Eniwetok locations and that at several widely scattered stations in the tropical Pacific that take rawinsondes it has become customary to enter 10 Cs persistently on the primary basis of presence of a moist layer high aloft and on a secondary basis of real or imagined visual observations, including a slight diminution of starlight that can equally well be attributed to the high moisture content of the lower air.

Cloud observations involving 10 Cs are not always reliable, as noted above. Low cloud heights are probably correct within 200 feet during daylight because of the high frequency of local air traffic. At night they are probably correct within 400 feet. Estimated middle cloud heights are probably correct within 2000 feet. All cloud-height values are given in hundreds of feet. Thus the entry "18" represents 1800 feet. Direction of cloud movement is to four points of the compass.

DDFF is given to 16 points of the compass, with speed in knots for one-minute intervals. Assuming no persistent bias, speeds are correct within 10% and directions are correct within 1 point (plus or minus).

T_xT_x and T_nT_n were taken from the hourly values. For this reason, on afternoons with few clouds the true T_xT_x may have been as much as 1° higher than those shown; while during the nighttime and very early morning T_nT_n may have been as much as 1° lower than the values shown whenever there were showers. (Lowest temperatures on tropical atolls are apt to occur momentarily during showers, evidently because of overturning of the air combined with the effect of evaporation.) This source of unreliability is additive to that for TT (above).

RR is accurate within 0.01 inch, assuming care was taken in the observations. In any event, the representativeness of the catch is a factor that lowers the reliability decidedly more than do any inaccuracies in measurement. (See Table 34 and the notes therefor. These make it clear that RR values in Table 4 are decidedly too low.)

TIMES OF RAINFALL are biased by one to a few minutes in that there was no recording gage and the observer would seldom notice to the minute (especially at night) the exact time of inception or termination of rain.

TABLE 5. FRED: RAWINSONDE OBSERVATIONS.

These Notes apply also to Table 20.

Date and Time refer to the 180th meridian. Where the time given is precisely 0000 or 1200 it represents the scheduled release time and may be in error by as much as 15 minutes. Otherwise, it is almost certainly correct within 5 minutes.

Level is correct within 5 mb., except for the more accurate surface value, which is taken from the station barometer (see Notes for Table 4).

Height values are correct within 20 m. for levels between 850 and 600 mb. (inclusive); within 30 m. between 500 and 300; within 50 m. at 200; and within 100 m. at 150 and 100 mb. These inaccuracies are in addition to those associated solely with estimating the pressure level (see above).

TT is correct within 1° C. up to 300 mb. and within 2° above 300 mb., assuming no gross instrument failure and no major error on the part of the observer.

RH is correct within 10% and most values are correct within 5%, except when values are in parentheses, when RH may be in error by as much as 20%.

DD is given to the nearest 10° and about 95% of the values shown give the true value to the nearest 10° interval. The remaining 5% are in error by a full 10° step.[3]

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[3]The values by 10° intervals are based on more accurate readings half of which may be in error by 1° or more. The 5% figure is based on the assumption that the error distribution is normal.

FF values are correct within 10-15%, the accuracy being greatest at lowest heights and least at greatest heights.

NOTE: The above estimates of the reliability of the various observations are based on considering both instrumental and observer errors, not including any consistent bias. Thus such factors were considered as accuracy of elevation and azimuth angles (instrumental) and the fact that in plotting there were inaccuracies introduced by the thickness of pencil lines.

TABLE 6. BRUCE: THREE-HOURLY OBSERVATIONS.

These Notes apply also to Tables 8, 21, and 24.

Date and Time refer to 180th meridian, and times given are correct within 5 minutes.

TT, TT_w, T_xT_x, and T_nT_n were all checked, one against the others, and minor adjustments were made in some instances in accordance with the following rules. Direct reading dry-bulb and wet-bulb temperatures were taken as being correct except in two instances (for all Tables

listed above), when a dry-bulb reading was obviously off by 5 degrees as indicated both by the recording hygrothermograph and the extreme thermometers. Where direct comparison immediately after re-setting showed consistently that a maximum or minimum thermometer differed from the direct-reading thermometer, the maximum or minimum value was corrected accordingly. Thus the minimum thermometer on KEITH during the first Intensive Phase was found to read 1° F. too low, and was consistently corrected by this amount. Except where otherwise noted in the Tables, all thermometers were read to the nearest half degree (values to the nearest .0 or .5). Since the psychron thermometers are designed and manufactured to be correct within 0.3° F. and since these were taken as being standard, the values are correct to within 0.5° F. (see Notes, Table 4).

RR values are correct within 0.01, not allowing for any sampling bias associated with exposure. The authors believe that the gages were well exposed and that there was no appreciable sampling bias due to exposure. The user of these data can judge from Figures 13 and 14 and from information in the text whether or not he agrees with this conclusion.

N is given in tenths, and except where the value is followed by "?" or is qualified by the Remarks, is correct within 0.1. Thus 0.5, representing the observer's best estimate, indicates a real value lying between 0.4 and 0.6, inclusive. It should be noted that N at these stations is often lower than N as observed at FRED because while FRED often reported 10Cs, BRUCE and KEITH seldom did so. Probably the FRED observation is in error in these instances (see Notes for Table 4).

C_{LMH} is a more or less accurate classification of cloud types and amounts, the accuracy varying with the observer. Some of the observers were inexperienced, having been trained in cloud observations only for a few hours prior to the start of the first observational period. Others were skilled observers, with many years of experience as well as thorough training. In general, the cloud identifications of the unskilled observers were nearly always correct with reference to recognition of cumulus and cirrus (undifferentiated); but probably they sometimes failed to recognize strato-cumulus, and particular types of cirrus and they probably sometimes confused altocumulus and cirro-cumulus or alto-stratus and cirro-stratus. Therefore in utilizing these observational data, reference should be made to the cloud photographs, to observations made simultaneously from other islets (including FRED), and to the following tabulation, which shows which observations in Table 6 were made by experienced observers.

Experienced observers made the observations at BRUCE during these intervals (all times are inclusive): 1200 Aug 24 -- 0900 Aug 25; 1200 Aug 26 -- 0900 Aug 27; 1200 Aug 28 -- 0900 Aug 29.

FF_3 gives mean windspeed in knots over the past three hours (since the time of last observation). The value shown was computed from the dial readings and was rounded off to the nearest whole knot. Fòr a discussion of anemometer calibrations, see Notes for Table 3.

DDFF gives wind direction to 8 points of the compass and windspeed in descriptive terms or in knots. Where descriptive terms or a range in knots is given, the windspeed was estimated by the observer. Where a single windspeed value is given it represents speed to the nearest knot as determined from the anemometer dial readings at the beginning and ending of one minute, unless some other time interval is specified in the Table. Descriptive terms follow the Beaufort phraseology. Estimated amounts (covering a range of speeds) are correct within 20% of the extremes shown where estimates were made by experienced observers (see above); otherwise, they are judged to be correct within 40%.

Times of beginning and end of rain are biased in the direction of giving too late a time in many instances. In this a distinction must be made between daytime and nighttime values. Daytime values are probably correct within 5 minutes. Nighttime values may be in error by as much as 30 minutes and there may well have been light showers that were not detected at night since the observer was often asleep. (On behalf of the observer it must be stated that these were 24- or 48-hour watches, with the observer alone on the islet.) Times of occurrence of phenomena other than beginning or end of rain are probably correct within 5 minutes. Here also, however, a distinction must be made between daytime and nighttime: There may well have been special phenomena that were not detected at night, not only because of poor visibility but also because the observer was in his tent asleep.

TABLE 7. BRUCE: SPECIAL OBSERVATIONS.

Date and Time refer to 180th meridian. Times are absolutely correct to within 5 minutes (allowing for error in setting of observer's watch) and are relatively correct (compared with one another) within 1 minute.

TT and TT_w were measured with a psychron, the instrument being held into the wind with the bulb shielded. Temperatures were estimated to the nearest tenth of a degree F. and are correct within 0.5° F.

Heights were estimated and are correct within 6 inches for the 5- and 3-foot heights and within 3 inches for the one-foot height.

TT_s was measured with an unshielded thermometer, graduated in half-degrees Centigrade. Readings were estimated to the nearest tenth degree C. and were converted to the nearest tenth degree F. The thermometer was held with the bulb continuously below the water surface, at a

depth of 3-6 inches. It is difficult to estimate what the accuracy of these observations was, but assuming that the instrument was correct within 0.2° C., that the observer's readings were correct within 0.2° C., that neither of these possible sources of error was consistently biased, and that both errors were distributed normally then 9 values out of 10 are correct within 0.3° F. and all are correct within 0.7° F.

TABLE 8. KEITH: THREE-HOURLY OBSERVATIONS.

See Notes for Table 6.

Experienced observers made the cloud and other observations during the following intervals (times are inclusive): 1200 Aug 18 -- 0900 Aug 19; 1200 Aug 21 -- 0900 Aug 23; 1200 Aug 26 -- 0900 Aug 27; 1200 Aug 28 -- 0900 Aug 29; 1200 Aug 30 -- 0900 Aug 31.

TABLE 9. KEITH: HOURLY RELATIVE HUMIDITIES.

This Note applies also to Tables 22 and 25.

The three-hourly values (0300, 0600, etc.) are based on direct dry-bulb and wet-bulb readings (Table 8). The remaining values are taken from hygrothermograph charts, with adjustments in absolute trace readings being made to fit the three-hourly values. The three-hourly values are all correct within 6% and 9 out of 10 are correct within 4% (see Notes, Table 4). For intermediate hourly values, these errors increase to 8% and 5%. Further, at values in the 80s there is a small bias -- about 1% -- in the direction of giving values that are too low; while in the 90s there is similar bias of about 2%.

Since the hygrothermograph was checked regularly (usually daily and at least every other day) times are correct within 15 minutes.

TABLE 10. MACK: DAILY OBSERVATIONS.

This Note applies also to Table 26.

The Notes for Table 6 apply for all items except RR, DDFF, Sea, and Remarks. Cloud, wind, sea, and other observations were made by experienced observers on all dates except August 26th through 29th.

RR. Unavoidably, the raingage was not well exposed (see General Notes and Figure 7). Therefore readings may be in error by as much as 20%, with values probably tending to be too low when the wind at time of rainfall was between NNW and NNE and too high when it was between SSW and SSE.

DDFF gives wind direction to 8 points and windspeed in knots. These are estimates only. Where a range in knots is given, the values may be taken as being correct within 20% of the extremes when the observer was experienced or 40% when he was not. Where a single speed figure is given, the values may be taken as being correct within 30% when the observer was experienced or 60% when he was not.

SEA conditions are described in the Remarks in instances in which there was any doubt as to what standard code number to apply.

Remarks give dry-bulb and wet-bulb readings on Platforms #1, 2, and 3. Platform #1 is the small, low platform at the southwest corner of FRED. Platform #2 is the large middle platform on the northern side, which has upon it the small shelter house. Platform #3 is that on the south side, on which the shelter and raingage were mounted. (See Figure 7.) These platform temperature observations were taken with a psychron at a height of 5 feet (plus or minus 6 inches) above the platform itself. The values are correct within 0.5° F.

TABLE 11. MACK: BI-HOURLY TEMPERATURES AND RELATIVE HUMIDITIES.

This Note applies also to Table 27.

For humidity values, the direct once-a-day RH derived from direct dry-bulb and wet-bulb readings were taken as being correct and the trace curve of the hygrothermograph was where necessary adjusted accordingly. Similarly, the thermograph trace was adjusted where necessary to fit the direct dry-bulb reading and also the maximum and minimum thermometer readings. In both instances the necessary adjustments (both for the first and second Intensive Phase), amounted to not more than 4% for RH or 2° F. for dry-bulb temperature. Usually, they were less than 2% and 1°.

It is estimated that all RH values are correct within 8% and that 9 out of 10 are correct within 5%. There was no discernible bias in the RH chart values at MACK for values below 90%. Above 90%, however, there appears to have been a bias of 1-2%, with the values being too low by this amount and with the greater bias at the higher values.

It is estimated that bi-hourly temperatures are correct within 1.5° F., an estimate based on the closeness of agreement with direct reading temperatures and with maximum and minimum thermometer readings. There is no evidence of bias in the thermograph trace.

Since the hygrothermograph was checked regularly (usually daily and at least every other day), times are correct within 15 minutes.

TABLE 12. ELMER: DAILY OBSERVATIONS.

These Notes apply also to Table 28.

Time refers to 180th meridian and is correct within 5 minutes.

TT and TT_w are given to the nearest 0.5° F. (.0 or .5) and are correct within 0.5°.

T_xT_x and T_nT_n are correct within 1° F. They were read to the nearest 0.5° (.0 or .5).

RR is correct within 0.01 assuming a representative catch. For exposure see General Notes, text, and Figure 8.

The Notes for Table 4 apply to N, C_{LMH}, and DDFF. Observations were by experienced observers on all dates except August 27-29, inclusive.

TABLE 13. ELMER: BI-HOURLY TEMPERATURES.

Bi-hourly temperatures are taken from the hygrothermograph, with the trace adjusted to fit the direct-reading (psychron) and maximum and minimum values. Values shown in the Table are all correct within 2° F. and from the close agreement between direct readings and thermograph readings it is estimated that 9 out of 10 values are correct within 1° F. The footnotes to the Table give extreme values not obtainable within 1° by interpolation from the bi-hourly values.

Since the hygrothermograph chart was usually checked daily (and always at least every other day) times are correct within 15 minutes.

TABLE 14. JANET: DAILY RAINFALL.

RR is accurate to 0.01 inch. Time is 180th meridian and is accurate to within 5 minutes. Exposure excellent (see General Notes).

TABLE 15. ELMER-MACK: LAGOON TRAVERSES.

ZONES are defined as follows:

ZONE 1 — Within 500 yards of ELMER

ZONE 2 -- Between 500 yards and 5 miles out from ELMER
(or, in two instances, from BRUCE)

ZONE 3 -- Between 5 and 8 miles out from ELMER

ZONE 4 -- Between 8 and 11 miles out from ELMER

ZONE 5 -- Within 500 yards of MACK

Placement within zones is certain in every instance except the following: On August 26th, the 1030 observation was near the boundary between Zones 3 and 4, and may have been a few hundred yards within 3, rather than in 4 as given. The same is true with reference to the 1015 observation on August 28th. In all instances except when the traverse originated at BRUCE,

the M-boat stayed within a zone bordered on the northeast by a line paralleling the direct ELMER-MACK track at a distance of 2 miles and bordered on the southwest by a line paralleling the direct track at a distance of 1 mile.

Time. Absolute times are correct within 10 minutes. Time intervals (between successive observations) are correct within 3 minutes, allowing for the fact that occasionally time was entered at the start of the observations although usually it was entered immediately upon their conclusion.

$\underline{TT_s}$ is correct within 0.2° F. in instances in which it was read to the nearest tenth of a degree and within 0.4 when read to the nearest half degree (.0 or .5). These estimates are based on the fact that the thermometer specifications call for an accuracy of within 0.1 and on the assumptions that this initial tolerance held and that the observer correctly read the thermometer within 0.1.

$\underline{TT}$ and $\underline{TT_w}$ were read to the nearest half-degree (.0 or .5) and are correct within 0.5° (see discussion under Notes, Table 4).

TABLE 16. BETWEEN BRUCE, KEITH, ELMER: LAGOON TRAVERSES.

Locations of the observations can be estimated by assuming straight-line courses between the islets and by spacing the observation points along these lines with distances proportional to elapsed times between observations. In most instances this will locate the observation point correctly to within 700 yards and in all instances it will locate the point correctly to within 1500 yards.

Times are absolutely correct within 10 minutes (180th meridian time) and differences between successive times are correct within 1 minute.

Temperatures were measured with different types of thermometers at different times, and the accuracy varied accordingly. Details are as follows:

August 20. Both air and water temperatures were measured with a mercury-in-glass thermometer, unjacketed, graduated in half-degrees C. and temperatures were estimated to 0.1° C. Values were later converted to the nearest 0.1° F. for water temperatures and the nearest 0.5° F. for air temperatures. Assuming no bias or instrumental error beyond the initial thermometer tolerance, $\underline{TT_s}$ values are accurate within 0.4° F. and $\underline{TT}$ values, within 0.6° F.

August 23. For all observations through that taken at 1420, the instrument, procedures, and accuracies were the same as for August 20 (above). From 1430 onward, a metal jacketed thermometer graduated in whole degrees F. was used. Using this thermometer, the observer estimated $\underline{TT_s}$ to the nearest 0.1° F. and $\underline{TT}$ to the nearest half-degree F. (.0 or .5). Since

this was a less reliable instrument than the centigrade thermometer, TT_s is judged to be accurate only within 0.5° F. and TT to be accurate only within 0.7° F.

August 28. TT_s, TT, and TT_w were all measured to the nearest half-degree F. (.0 or .5). The Fahrenheit thermometer described immediately above was used to measure TT_s, and the resulting observations are correct within 0.7° F. TT and TT_w are correct within 0.5° F. (see Notes, Table 4).

August 31. TT_s, measured to tenths C. (see August 20, above), are accurate within 0.4° F. TT and TT_w, measured with a psychron to the nearest half-degree F., are accurate within 0.5° F.

TABLE 17. LAGOON-OCEAN: LAGOON-OCEAN TRAVERSES.

August 18. TT_s was obtained by canvas bucket-haul from a helicopter using the Centigrade thermometer described in the Notes for Table 16, above. Readings were to the nearest 0.1° C. Values given are correct within 0.4° F.

August 23. TT_s was measured to the nearest half-degree F., using the F. thermometer described under date of August 23 in Notes, Table 16, above. All values are accurate within 0.7° F. TT and TT_w were measured to the closest half-degree F. (.0 or .5) using a psychron. Values are accurate within 0.5° F. Locations in the ocean (outside) were all taken 500 to 1000 yards off the reef.

TABLE 18. ENIWETOK-BIKINI: BI-HOURLY OBSERVATIONS, MSTS - T-LST 618.

Time is correct within 5 minutes.

Positions while underway, as given in the log, may be assumed to be accurate within 2 nautical miles.

N_8 is correct within one-eighth. E.g.: In extreme instances, an entry of "4" may in fact have been 3/8 or 5/8.

DD is given to the nearest 10°, with the unit 0 omitted. Thus 11 represents 110°. With the ship underway, DD was estimated correctly to within 10°. With the ship docked, to within 8°. Thus in both instances a minority of the observations may fall in the wrong 10° category (plus or minus).

FF is given to the nearest knot. With the ship underway, FF was estimated correctly to within 5 knots (plus or minus). With the ship docked, to within 3 knots. Windspeeds (and directions) were estimated primarily on the basis of the effect of wind upon the water, following the Beaufort scale and then estimating knots within the Beaufort interval.

WX is given in code, following the U. S. Dept. of Commerce Weather Bureau Ship Code Card (TA 631-0-2), dtd. January 1, 1955. Quoting from this source, the code values given are to be interpreted as follows:

01: No hydrometeors except clouds. Clouds generally dissolving or becoming less developed during the past hour.

02: No hydrometeors except clouds. State of sky on the whole unchanged during the past hour.

03: No hydrometeors except clouds. Clouds generally forming or developing during the past hour.

15: Precipitation within sight, reaching sea, but distant ((i.e., estimated to be more than 5 km. (3 miles) from ship)).

16: Precipitation within sight, reaching sea, near to but not at the ship.

18: Squall(s).

60: Rain, not freezing, intermittent - slight at time of observation.

80: Rain shower(s), slight.

81: Rain shower(s), moderate or heavy.

P shows air pressure in tenths and hundredths of inches, so that the values given in the Table should be preceded by 29. Values given are correct within 0.05 inch.

TT and TT_W are correct within 1° F.

C_L amounts are correct within one-eighth. Height estimates are judged to be correct within 500 feet. Codes, as taken from the U. S. Dept. of Commerce Weather Bureau Ship Code Card (TA 631-0-2), dtd. January 1, 1955, have the following meanings:

2: Cumulus of moderate or strong vertical development generally with protuberances in the form of domes or towers, either accompanied or not by other cumulus or by stratocumulus; all having their bases at the same level.

3: Cumulonimbus the summits of which, at least partially, lack sharp outlines, but are neither clearly fibrous, neither cirriform nor in the form of an anvil; cumulus, stratocumulus or stratus may be present.

7: Fractostratus of bad weather or fractocumulus of bad weather or both; usually below altostratus or nimbostratus.

C_M and C_H code entries have meanings as follows (from the source cited immediately above):

C_M: 1: Altostratus, the greater part of which is semitransparent; through this part the sun or moon may be weakly visible as through ground glass.

$\underline{C_M}$: 4: Patches of semitransparent altocumulus (often in the shape of almonds or fishes) at one or more levels; cloud elements continuously changing in aspect.

5: Semitransparent altocumulus in bands or altocumulus in one more or less continuous layer progressively invading the sky, generally thickening as a whole; the layer may be opaque or double with a second sheet.

6: Altocumulus formed by the spreading out of cumulus.

7: Any one of the following cases: (a) Altocumulus in two or more layers usually opaque in places and not progressively invading the sky; (b) Opaque layer of altocumulus not progressively invading the sky; (c) Altocumulus coexisting with altostratus or nimbostratus or both.

9: Altocumulus, generally at several layers in a chaotic sky; dense cirrus is usually present.

$\underline{C_H}$: 1: Cirrus in the form of filaments, strands or hooks, not progressively invading the sky (often called "mares tails").

2: Dense cirrus in patches or entangled sheaves usually not increasing and possibly the remains of the upper parts of cumulonimbus; or cirrus with sproutings in the form of towers or battlements or having the aspect of cumuliform tufts.

3: Cirrus, often in the form of an anvil; either the remains of the upper parts of cumulonimbus, or parts of distant cumulonimbus, the cumuliform portions of which cannot be seen.

8: Cirrostratus not progressively invading the sky, and not completely covering it.

9: Cirrocumulus alone, or cirrocumulus accompanied by cirrus or cirrostratus or both, but cirrocumulus is the predominant cirriform cloud.

DD for waves is given to 10°, with the unit 0 omitted from the entries. Thus 08 represents 80°. Directions are correct to plus or minus 10°.

Period of waves is given in seconds and is correct within one second.

Height of waves is given in feet and is correct within 50% (plus or minus).

PLACE: FRED

HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957

TABLE 4

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/18	0056	770	81.3	77.0	82	10	1CuE18	10Cs	0	0	2	ESE4				
	0157	760	81.0	77.8	87	10	1CuE18	10Cs	0	0	2	ESE2				
	0255	735	81.0	78.0	88	10	1CuE18	10Cs	0	0	2	ESE4				
	0354	725	81.0	78.0	88	10	1CuE18	10Cs	0	0	2	ESE6				
	0456	720	81.9	78.2	85	10	2CuE18	10Cs	0	0	3	SSE6				
	0555	720	82.0	78.0	84	10	2CuE18	10Cs	0	0	3	SSE5				
	0655	725	82.0	78.0	84	10	2CuE18	10Cs	0	0	3	SSE6				
	0756	745	83.0	79.0	84	10	2CuE18	10Cs	0	0	3	SSE8				
	0855	775	84.0	79.0	80	10	2CuE18	10Cs	0	0	3	ESE6				
	0956	780	84.0	79.0	80	10	1CuE18	10Cs	0	0	2	SE8				
	1055	790	84.0	79.0	80	10	1CuE18	10Cs	0	0	2	SE8				
	1155	770	86.0	80.0	77	10	1CuE18	10Cs	0	0	2	SE9				
	1255	765	87.5	81.5	78	10	1CuE18	10Cs	0	0	2	SE8				
	1355	750	87.5	81.5	78	10	1CuE18	10Cs	0	0	2	SE7				
	1455	745	88.0	82.0	77	10	1CuE18	10Cs	0	0	2	SE6				
	1555	735	88.0	83.0	81	10	1CuE18	10Cs	0	0	2	SE7				
	1658	735	86.5	79.0	72	10	1CuE18	10Cs	0	0	2	S5				
	1755	745	86.0	78.0	73	10	1CuE18	10Cs	0	0	1	SSE4				
	1856	755	84.5	78.0	75	10	1CuE18	10Cs	0	0	1	SE4				
	1958	775	83.0	78.0	80	10	1CuE18	10Cs	0	0	1	SE2				
	2056	780	83.5	78.5	80	10	1CuE18	10Cs	0	0	1	ESE7				
	2158	800	83.0	78.0	80	10	1CuE18	10Cs	0	0	1	E7				
	2256	805	83.0	78.0	80	10	2CuE18	10Cs	0	0	3	E4				
	2357	805	82.8	78.0	81	10	2CuE18	10Cs	0	0	2	E6		88	81	0
8/19	0056	785	82.8	76.0	81	1	1CuE18	0	0	0	1	E8				
	0158	775	82.5	78.0	82	3	3CuE18	0	0	0	3	E6				
	0255	770	82.5	78.0	82	3	3CuE18	0	0	0	3	ENE7				
	0357	760	82.0	77.0	80	2	2CuE18	0	0	0	2	ENE7				
	0455	760	82.1	77.0	79	2	2CuE18	0	0	0	2	ENE7				
	0558	745	81.7	76.9	80	2	2CuE18	0	0	0	2	ENE8				
	0659	750	82.0	79.0	88	10	2CuE18	10Cs	0	0	2	ENE9				
	0755	760	85.0	80.0	81	10	2CuE18	10Cs	0	0	2	E8				
	0855	750	86.0	81.0	81	10	2CuE18	10Cs	0	0	2	E10				
	0955	795	86.0	81.0	81	10	2CuE18	10Cs	0	0	2	E8				
	1055	795	86.0	81.0	81	10	2CuE18	10Cs	0	0	2	E11				
	1155	800	86.0	81.0	81	10	2CuE18	10Cs	0	0	2	E11				
	1256	795	88.0	82.0	77	10	2CuE18	10Cs	0	0	2	E14				
	1355	790	88.0	82.0	77	10	2CuE18	10Cs	0	0	2	E12				
	1455	775	88.0	83.0	81	10	2CuE18	10Cs	0	0	2	E10				
	1556	765	87.0	81.0	77	10	2CuE18	10Cs	0	0	2	E11				
	1657	760	87.0	80.5	75	10	2CuE18	10Cs	0	0	2	E10				
	1756	745	87.0	79.0	70	10	2CuE18	10Cs	0	0	2	E11				

PLACE: FRED

HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957

TABLE 4 (Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/19	1855	745	85.4	79.0	76	10	2CuE18	10Cs	0	0	2	E10				
	1959	755	84.0	78.0	77	10	2CuE18	10Cs	0	0	2	E10				
	2056	765	83.6	78.0	78	10	2CuE18	10Cs	0	0	2	E11				
	2157	780	82.8	77.8	80	10	2CuE18	10Cs	0	0	2	E10				
	2256	790	82.6	78.0	81	10	2CuE18	10Cs	0	0	2	E11				
	2358	810	83.0	78.3	81	10	2CuE18	10Cs	0	0	2	E13		88	82	0
8/20	0057	805	83.0	78.3	81	10	1CuE18	10Cs	0	0	1	E11				
	0156	785	82.5	78.0	82	10	1CuE18	10Cs	0	0	1	E15				
	0259	775	82.3	77.7	81	10	1CuE18	10Cs	0	0	1	E10				
	0357	760	82.1	77.5	81	10	2CuE18	10Cs	0	0	2	E10				
	0457	760	82.0	77.5	82	10	3CuE18	10Cs	0	0	3	E11				
	0559	750	81.6	77.0	81	10	3CuE18	10Cs	0	0	3	E11				
	0658	755	82.0	78.0	83	10	2CuE18	10Cs	0	0	3	E10				
	0758	770	83.0	77.5	78	10	3CuE18	10Cs	0	0	3	E16				
	0855	790	84.0	77.8	76	10	2CuE18	1Sc 45	10Cs	0	4	E16				
	0956	805	85.0	78.0	73	10	2CuE18	10Cs	0	0	3	E14				
	1058	805	86.5	78.5	70	10	2CuE18	10Cs	0	0	3	E16				
	1155	820	87.0	79.0	70	10	2CuE18	10Cs	0	0	3	E10				
	1256	810	86.5	79.0	72	10	2CuE18	10Cs	0	0	3	E14				
	1356	795	86.5	79.0	72	10	1CuE18	10Cs	0	0	2	E9				
	1455	775	87.0	80.0	74	10	1CuE18	10Cs	0	0	2	E8				
	1557	755	87.8	78.0	65	10	1CuE18	10Cs	0	0	2	E8				
	1656	755	87.0	79.0	70	10	1CuE18	10Cs	0	0	2	E6				
	1757	750	86.5	79.0	72	10	1CuE18	10Cs	0	0	2	E6				
	1856	760	85.5	78.5	73	10	1CuE18	10Cs	0	0	2	E9				
	1957	775	83.5	78.3	79	10	1CuE18	10Cs	0	0	2	E10				
	2055	795	83.2	78.0	79	10	1CuE18	10Cs	0	0	2	E8				
	2156	810	83.0	78.5	82	10	1CuE18	10Cs	0	0	2	E8				
	2256	820	83.2	78.5	81	10	1CuE18	10Cs	0	0	2	E8				
	2357	835	83.0	78.5	82	10	1CuE18	10Cs	0	0	2	E8		88	82	0
8/21	0056	830	82.5	77.5	80	10	5CuE18	10Cs	0	0	5	ESE8	0039-0049			
	0156	805	82.0	77.5	81	10	5CuE18	10Cs	0	0	5	ESE10				
	0256	790	79.0	77.5	93	10	7CuE18e	10Cs	0	0	8	S13	0200-0309			
	0355	780	80.0	77.8	91	10	5CuE18	10Cs	0	0	5	S10				
	0457	780	81.2	77.5	85	10	4CuE18	10Cs	0	0	5	S16				
	0559	790	81.8	77.6	83	10	4CuE18	10Cs	0	0	5	S12				
	0656	800	81.0	78.0	87	10	5CuE18	6AcE160e	10Cs	0	9	S9				
	0755	800	82.0	78.0	84	10	5CuE18	6AcE160e	10Cs	0	9	S16				
	0855	920	83.0	79.0	84	10	5CuE18	6AcE160e	10Cs	0	9	S15				
	0955	820	82.0	80.0	91	10	5CuE18	6AcE160e	10Cs	0	9	S16				
	1058	820	82.5	78.5	84	10	3CuE18	4ScE45b	10Cs	0	8	S16				

PLACE: FRED

HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957

TABLE 4 (Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/21	1158	795	83.0	79.5	86	10	3CuE18	4ScE45	2AcE160e	10Cs	7	S11				
	1255	800	83.0	79.5	86	10	2CuE18	4ScE45	2AcE160e	10Cs	7	S17				
	1355	785	84.0	80.0	84	10	2CuE18	4AcE160e	10Cs	0	9	S16				
	1458	775	84.5	78.5	77	10	2CuE18	4AcE160e	10Cs	0	8	SSW16				
	1559	770	84.1	78.3	77	10	2CuE18	3AcE160	10Cs	0	8	SSW13				
	1658	755	84.0	79.0	80	10	2CuE18	3AcE160	10Cs	0	8	S10				
	1755	740	84.0	78.8	80	10	1CuE18	3AcE160	10Cs	0	7	SSW12				
	1857	745	83.5	78.0	78	10	1CuE18	3AcE160	10Cs	0	6	S11				
	1958	780	83.2	78.0	79	10	1CuE18	3AcE160	10Cs	0	6	S15				
	2057	795	83.2	78.0	79	10	2CuE18	1AcE160	10Cs	0	5	S9				
	2155	820	83.1	77.8	79	10	2CuE18	1AcE160	10Cs	0	3	S7				
	2257	830	82.9	77.8	80	10	2CuE18	10Cs	0	0	3	S10				
	2355	835	82.3	78.0	83	10	1CuE18	10Cs	0	0	2	S6		85	79	0.15
8/22	0056	825	82.0	78.8	87	10	1CuE18	10Cs	0	0	2	SW4				
	0156	810	82.0	77.0	80	10	1CuE18	10Cs	0	0	2	W4				
	0255	800	81.8	77.5	82	10	1CuE18	10Cs	0	0	2	W2				
	0356	775	81.2	77.0	82	10	2CuE18	10Cs	0	0	3	W4				
	0456	745	80.5	77.0	85	10	2CuE18	10Cs	0	0	3	SW8				
	0555	730	81.0	77.0	83	10	3CuE18	10Cs	0	0	4	SW10				
	0656	740	81.0	77.0	83	10	3CuE18	10Cs	0	0	4	SW8				
	0756	760	82.0	78.0	84	10	3CuE18	10Cs	0	0	4	SW4				
	0855	775	84.0	80.0	84	10	3CuE18	10Cs	0	0	4	NW8				
	0955	795	86.0	80.0	77	10	3CuE18	10Cs	0	0	4	NNE4				
	1058	805	80.5	78.0	89	10	3CuE18	3ScE45e	2AsE160	10Cs	8	NNE12	1004-1128			
	1156	800	82.0	78.0	84	10	3CuE18	3ScE45b	2AsE160	10Cs	8	NE8				
	1255	785	82.0	78.0	84	10	3CuE18	3ScE45b	2AsE160	10Cs	8	NE10				
	1356	755	85.0	81.0	84	10	3CuE18	3ScE45b	2AsE160	10Cs	8	NE11				
	1455	745	88.0	78.5	66	10	3CuE18	3AcE140	10Cs	0	6	NE8				
	1556	730	87.8	79.0	68	10	2CuE18	3AcE140	2AsE160	10Cs	7	NE11				
	1657	720	86.7	78.5	70	10	2CuE18	2AcE140	10Cs	0	6	NE10				
	1756	725	84.8	78.5	75	10	2CuE18	3AcE140	10Cs	0	7	E10				
	1856	735	84.0	78.0	77	10	2CuE18	2AcE140	10Cs	0	7	ENE8				
	1958	740	83.5	77.0	74	10	2CuE18	2AcE140	1AsE160	10Cs	8	ENE12				
	2056	755	83.0	77.2	77	10	2CuE18	2AcE140	1AsE160	10Cs	7	NE11				
	2158	780	82.6	77.0	78	10	2CuE18	2AcE140	10Cs	0	6	NE10				
	2256	790	82.3	77.1	79	10	2CuE18	2AcE140	10Cs	0	6	NE11				
	2355	805	83.0	78.0	80	10	2CuE18	1AcE140	10Cs	0	6	ENE22		88	81	0.01
8/23	0054	785	82.0	79.0	88	10	2CuE18	1AcE140	10Cs	0	6	ENE12				
	0156	765	82.3	78.5	84	10	3CuE18	1AcE140	10Cs	0	7	E10				
	0255	760	82.0	78.0	84	10	3CuE18	2AcE140	10Cs	0	8	E6	0210-0229			
	0357	745	82.0	78.3	85	10	3CuE18	2AcE140	10Cs	0	9	E10	0315-0336			

PLACE: FRED HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957

TABLE 4
(Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/23	0458	740	79.8	77.3	90	10	3CuE18	2AcE140	10Cs	0	9	ENE10	0435-0507			
	0555	715	80.3	76.5	84	10	3CuE18	2AcE140	10Cs	0	8	ENE12				
	0655	715	80.3	76.5	84	10	3CuE18	2AcE140	10Cs	0	8	ENE10				
	0755	730	81.0	78.0	87	10	3CuE18	2AcE140	10Cs	0	8	ENE8				
	0855	735	82.0	79.0	88	10	3CuE18	2AcE140	10Cs	0	8	ENE8				
	0955	745	82.0	79.0	88	10	3CuE18	2AcE140	10Cs	0	8	ENE11	0954-0956			
	1058	745	83.5	80.0	86	10	2CuE18	3AcE140	10Cs	0	6	NE14				
	1155	740	84.5	80.0	82	10	2CuE18	3AcE140	10Cs	0	6	ENE14				
	1255	750	84.5	80.0	82	10	2CuE18	3AcE140	10Cs	0	6	ENE12				
	1355	715	86.0	83.0	88	10	2CuE18	3AcE140	10Cs	0	6	ENE13				
	1455	695	87.0	84.0	88	10	2CuE18	3AcE140	10Cs	0	6	ENE14				
	1556	675	85.5	81.0	82	10	2CuE18	1AsE160	10Cs	0	6	SE13				
	1657	675	84.0	80.0	84	10	2CuE18	1AsE160	10Cs	0	6	SSE13				
	1755	680	83.5	80.0	86	10	3CuE18	2ScE50	10Cs	0	8	SSE16				
	1857	685	81.8	79.2	89	10	5CuE18	4ScE50e	10Cs	0	8	SE14				
	1956	700	82.0	79.0	88	10	6CuE16m	6ScE50	10Cs	0	9	SE13				
	2058	720	82.0	79.0	88	10	6CuE16m	6ScE50	10Cs	0	8	SSE13				
	2159	760	81.8	79.2	89	10	6CuE16m	4ScE50	10Cs	0	8	SE12				
	2256	765	82.0	79.0	88	10	4CuE18	3ScE50e	10Cs	0	7	SE11				
	2355	795	83.0	81.0	84	10	3CuE18	2ScE50	10Cs	0	7	SE14		87	80	0.41
8/24	0055	785	83.0	79.0	84	10	3CuE18	2ScE50	10Cs	0	7	SE12				
	0156	775	82.5	78.3	83	10	3CuE18	2AcE140	10Cs	0	7	SE13				
	0255	760	82.3	78.0	83	10	3CuE18	2AcE140	10Cs	0	6	SE14				
	0355	755	82.0	78.3	85	10	3CuE18	2AcE140	10Cs	0	6	SE12				
	0456	750	81.5	77.0	81	10	2CuE18	2AcE140	10Cs	0	6	SE10				
	0555	740	81.3	78.0	86	10	2CuE18	2AcE140	10Cs	0	6	SE10				
	0658	760	81.0	78.5	89	10	3CuE18	2AcE140	10Cs	0	6	SSE10				
	0758	770	81.5	77.5	83	10	3CuE18	1AcE140	10Cs	0	6	SE6				
	0855	800	83.0	79.5	86	10	3CuE18	1AcE140	10Cs	0	6	SSE8				
	0955	815	83.0	80.5	90	10	6CuE18b	10Cs	0	0	8	S12	0928-0935			
	1055	820	84.5	80.5	84	10	6CuE18b	10Cs	0	0	6	S6	1009-1011			
	1155	815	85.5	80.0	79	10	4CuE18	10Cs	0	0	5	SE3				
	1256	805	87.0	80.0	74	10	2CuE18	10Cs	0	0	4	ESE5				
	1356	785	87.2	80.0	73	10	5CuE18	10Cs	0	0	6	ESE6				
	1458	770	87.0	81.0	77	10	5CuE18	10Cs	0	0	6	E6				
	1557	750	86.0	81.0	81	10	3CuE18	10Cs	0	0	5	E10				
	1658	740	86.1	81.0	80	10	3CuE18	10Cs	0	0	5	E10				
	1756	735	86.1	81.0	80	10	3CuE18	10Cs	0	0	5	E8				
	1857	745	84.2	79.5	81	10	3CuE18	10Cs	0	0	5	E8				
	1957	765	84.0	79.4	82	10	3CuE18	10Cs	0	0	5	E11				
	2059	775	83.7	79.0	81	10	3CuE18	10Cs	0	0	3	E15				
	2158	805	83.1	78.7	82	10	2CuE18	10Cs	0	0	3	E14				

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HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957

TABLE 4 (Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/24	2256	810	82.9	78.6	83	10	2CuE18	10Cs	0	0	3	E11				
	2357	815	82.9	78.6	83	10	2CuE18	10Cs	0	0	3	E10		87	81	0.05
8/25	0056	795	82.2	77.0	79	10	2CuE18	10Cs	0	0	2	E10				
	0156	790	82.0	77.1	80	10	2CuE18	10Cs	0	0	2	E12				
	0256	785	82.3	77.0	79	10	2CuE18	10Cs	0	0	2	E10				
	0356	780	82.2	77.0	79	10	2CuE18	10Cs	0	0	2	E11				
	0458	790	82.0	77.1	80	10	2CuE18	10Cs	0	0	2	E12				
	0556	795	82.3	77.0	79	10	2CuE18	10Cs	0	0	2	E10				
	0658	790	82.0	77.1	80	10	2CuE18	10Cs	0	0	5	E6				
	0755	795	82.0	77.1	80	10	2CuE18	10Cs	0	0	5	E6				
	0855	810	82.0	77.1	80	10	2CuE18	10Cs	0	0	5	E8				
	0958	825	86.0	79.0	73	10	2CuE18	10Cs	0	0	5	E6				
	1055	825	86.0	81.0	80	10	2CuE18	10Cs	0	0	5	E8				
	1155	805	86.0	81.0	80	10	2CuE18	10Cs	0	0	5	E6				
	1255	815	87.0	82.0	81	10	2CuE18	10Cs	0	0	4	E8				
	1355	795	88.0	79.0	67	10	2CuE18	10Cs	0	0	4	E5				
	1455	775	88.0	79.0	67	10	2CuE18	10Cs	0	0	4	E6				
	1555	765	88.3	79.0	67	10	2CuE18	10Cs	0	0	5	E4				
	1656	755	87.0	78.5	69	10	3CuE18	10Cs	0	0	6	E4				
	1755	725	86.5	78.3	69	10	3CuE18	10Cs	0	0	6	ESE2				
	1855	755	85.0	78.0	73	10	2CuE18	2AcE140	10Cs	0	6	C				
	1956	755	83.8	77.0	73	10	2CuE18	1AcE140	10Cs	0	5	C				
	2055	760	83.3	77.2	76	10	2CuE18	1AcE140	10Cs	0	4	C				
	2158	770	83.2	77.0	75	10	2CuE18	1AcE140	10Cs	0	4	N5				
	2256	775	82.8	77.5	79	10	2CuE18	10Cs	0	0	3	NNE4				
	2357	765	82.6	77.5	79	10	2CuE18	10Cs	0	0	2	N2		88	82	0
8/26	0057	755	82.6	77.5	79	10	2CuE18	10Cs	0	0	2	NNE2				
	0157	730	82.3	77.6	81	10	3CuE18	5As 160e	10Cs	0	8	E11	0139-0146			
	0257	710	82.2	77.4	80	10	3CuE18	5As 160e	10Cs	0	8	C				
	0356	705	82.0	77.1	80	10	2CuE18	5Cs	0	0	2	E5				
	0456	700	81.7	77.0	81	10	2CuE18	10Cs	0	0	2	E5				
	0559	690	81.3	76.6	80	10	2CuE18	10Cs	0	0	2	E6				
	0655	710	82.0	79.0	88	10	2CuE18	10Cs	0	0	2	E5				
	0755	710	82.0	79.0	88	10	2CuE18	10Cs	0	0	2	E4				
	0855	720	82.0	79.0	88	10	2CuE18	10Cs	0	0	2	E6				
	0958	735	83.5	79.0	82	10	6CuE18e	10Cs	0	0	6	E4	0945-0947			
	1058	745	86.5	80.5	77	10	2CuE18	10Cs	0	0	3	ESE5				
	1155	765	86.5	80.5	77	10	2CuE18	10Cs	0	0	6	S3	1129-1131			
	1255	760	86.5	80.5	77	10	2CuE18	10Cs	0	0	6	S5				
	1356	740	88.0	83.0	81	10	2CuE18	10Cs	0	0	6	S6				
	1456	720	86.5	80.0	75	10	4CuE18	10Cs	0	0	6	SE6				

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HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957

TABLE 4
(Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/26	1557	710	86.7	80.0	75	10	3CuE18	10Cs	0	0	6	SE3				
	1658	705	86.5	80.0	75	10	3CuE18	10Cs	0	0	6	SE3				
	1756	700	85.0	79.0	77	10	3CuE18	10Cs	0	0	6	SE2				
	1856	705	84.3	78.2	76	10	3CuE18	10Cs	0	0	6	E4	1819-1824			
	1955	720	84.0	78.0	76	10	3CuE18	10Cs	0	0	6	E3				
	2058	735	83.4	78.1	79	10	3CuE18	10Cs	0	0	6	E16				
	2158	745	83.0	77.6	78	10	3CuE18	10Cs	0	0	6	E4				
	2256	755	83.1	77.7	78	10	3CuE18	10Cs	0	0	6	E4				
	2355	760	83.0	78.0	80	10	3CuE18	10Cs	0	0	4	E10		88	81	0.02
8/27	0054	755	83.0	78.0	80	10	3CuE18	10Cs	0	0	4	ESE10				
	0157	750	83.0	78.5	82	10	3CuE18	10Cs	0	0	4	ESE10				
	0255	730	82.0	78.0	84	10	3CuE18	10Cs	0	0	4	E10	0224-0232			
	0357	725	79.5	77.3	91	10	3CuE18	10Cs	0	0	4	E10	0328-0336			
	0456	720	81.0	78.0	83	10	3CuE18	10Cs	0	0	4	SE12				
	0555	710	80.3	77.9	90	10	3CuE18	10Cs	0	0	4	ESE12				
	0655	715	80.3	77.9	90	10	3CuE18	10Cs	0	0	4	ESE16				
	0755	730	82.0	79.0	88	10	3CuE18	10Cs	0	0	4	ESE15				
	0855	745	82.0	79.0	88	10	3CuE18	10Cs	0	0	4	ESE15	0829-0839			
	0955	755	83.0	80.0	88	10	3CuE18	10Cs	0	0	4	ESE15	0904-0909			
	1055	770	84.0	80.0	84	10	3CuE18	10Cs	0	0	4	ESE15	1009-1032			
	1155	755	83.8	80.0	85	10	4CuE18	10Cs	0	0	6	E16	1104-1134			
	1255	740	83.8	80.0	85	10	4CuE18	10Cs	0	0	6	E15	1223-1230			
	1355	725	86.0	82.0	84	10	4CuE18	10Cs	0	0	6	E14				
	1455	715	86.0	82.0	84	10	4CuE18	10Cs	0	0	6	E15				
	1557	700	87.0	78.3	68	10	2CuE18	10Cs	0	0	2	E12				
	1658	690	87.1	78.5	68	10	2CuE18	10Cs	0	0	2	E12				
	1756	700	87.0	78.3	68	10	2CuE18	10Cs	0	0	2	E11				
	1855	725	86.6	79.1	72	10	1CuE18	10Cs	0	0	1	E8				
	1957	755	86.5	79.0	72	10	3CuE18	10Cs	0	0	3	E10				
	2058	760	86.5	79.0	72	10	2CuE18	10Cs	0	0	2	ESE9				
	2157	785	85.3	78.2	73	10	2CuE18	10Cs	0	0	2	ESE10				
	2256	795	83.7	77.4	75	10	2CuE18	10Cs	0	0	2	ESE8				
	2359	800	83.1	76.9	75	10	2CuE18	10Cs	0	0	2	ESE10		87	80	0.50
8/28	0056	795	83.0	78.0	80	10	3CuE18	10Cs	0	0	3	SSE9				
	0158	775	83.0	78.5	82	10	3CuE18	10Cs	0	0	3	SE10				
	0256	765	82.0	78.0	84	10	3CuE18	10Cs	0	0	3	SSE8				
	0359	750	82.0	78.0	84	10	2CuE18	10Cs	0	0	2	SE6				
	0455	750	82.3	76.0	75	10	2CuE18	10Cs	0	0	2	SSE6				
	0557	750	82.2	78.1	83	10	2CuE18	10Cs	0	0	2	SSE8				
	0655	760	82.2	78.1	83	10	2CuE18	10Cs	0	0	2	SSE6				
	0755	770	83.5	80.0	86	10	2CuE18	10Cs	0	0	2	SSE7				

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HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957

TABLE 4 (Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/28	0858	770	83.8	78.5	79	10	2CuE18	10Cs	0	0	6	S8				
	0955	805	83.8	78.5	79	10	2CuE18	10Cs	0	0	6	S6				
	1058	815	85.0	80.0	80	10	3CuE18	10Cs	0	0	5	S6				
	1155	920	85.0	80.0	80	10	3CuE18	2ScE45	10Cs	0	7	SSE4				
	1255	815	85.0	80.0	80	10	3CuE18	2ScE45	10Cs	0	7	SSE4				
	1355	810	87.0	82.0	81	10	3CuE18	2ScE45	10Cs	0	7	ESE5				
	1455	815	87.0	81.0	77	10	3CuE18	2ScE45	10Cs	0	7	ESE2				
	1554	790	85.0	79.3	78	10	2CuE18	3ScE45	10Cs	0	9	ENE6				
	1657	790	84.3	79.0	79	10	2CuE18	3ScE45	10Cs	0	9	ENE8				
	1757	765	84.1	79.0	80	10	2CuE18	3ScE45	10Cs	0	8	ENE7				
	1856	775	82.0	78.3	85	10	2CuE18	1ScE45	2As 140	10Cs	8	ENE10				
	1955	790	81.7	78.0	84	10	2CuE18	2As 140	10Cs	0	7	ENE12				
	2055	810	81.5	78.0	86	10	2CuE18	2As 140	10Cs	0	7	ENE14				
	2158	825	81.5	77.5	83	10	2CuE18	2As 140	10Cs	0	7	ENE12				
	2256	835	81.3	77.8	85	10	2CuE18	2As 140	10Cs	0	7	ENE10				
	2359	840	81.2	77.5	85	10	2CuE18	2As 140	10Cs	0	6	ENE11		87	81	0
8/29	0057	830	81.2	77.5	82	10	3CuE18	1As 140	10Cs	0	5	E10				
	0156	815	82.0	78.0	84	10	2CuE18	10Cs	0	0	4	E9				
	0255	805	81.7	77.5	83	10	2CuE18	10Cs	0	0	2	E11				
	0357	800	82.1	77.5	81	10	1CuE18	10Cs	0	0	1	E7				
	0457	795	81.8	77.3	81	10	1CuE18	1As 140	0	0	1	E11				
	0558	790	81.4	77.0	82	10	2CuE18	1As 140	10Cs	0	3	E10				
	0655	790	81.4	77.0	82	10	2CuE18	1As 140	10Cs	0	3	E9				
	0755	790	82.0	79.0	88	10	2CuE18	10Cs	10Cs	0	3	E10				
	0855	810	84.0	80.0	84	10	2CuE18	10Cs	0	0	2	E8				
	0955	815	84.0	80.0	84	10	2CuE18	10Cs	0	0	2	E8				
	1056	820	87.0	80.0	74	10	1CuE18	10Cs	0	0	1	ENE8				
	1156	815	87.0	81.0	77	10	2CuE18	10Cs	0	0	2	ENE6				
	1255	820	87.0	81.0	77	10	2CuE18	10Cs	0	0	2	ENE8				
	1356	800	88.0	82.0	78	10	2CuE18	10Cs	0	0	2	E14				
	1455	790	88.0	80.0	71	10	2CuE18	10Cs	0	0	2	ENE12				
	1556	775	89.5	80.0	66	10	2CuE18	10Cs	0	0	2	NE12				
	1655	760	86.0	79.0	73	10	6CuE16b	10Cs	0	0	6	ENE18				
	1756	750	84.0	80.0	84	10	5CuE18	10Cs	0	0	5	NNE15	1659-1710			
	1855	760	81.5	78.0	85	10	6CuE18e	2ScE45	10Cs	0	7	NE14	1842-1854			
	1956	775	83.5	77.0	74	10	5CuE18	2ScE45e	10Cs	0	8	NE11				
	2055	780	83.0	79.0	84	10	4CuE18	2ScE45e	10Cs	0	7	NE10				
	2158	790	83.0	79.0	84	10	3CuE18	1ScE45	10Cs	0	6	ENE16	2054-2100			
	2257	795	83.0	78.0	80	10	3CuE18	1ScE45	10Cs	0	6	NE12				
	2358	805	83.0	78.0	80	10	3CuE18	1ScE45	10Cs	0	6	NE10		90	81	0.01

PLACE: FRED HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957 TABLE 4 (Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/30	0055	775	83.0	76.0	73	10	2CuE18	10Cs	0	0	2	E13				
	0157	780	82.0	78.0	84	10	2CuE18	10Cs	0	0	4	E10				
	0258	760	82.5	78.3	83	10	2CuE18	10Cs	0	0	3	E11				
	0356	750	82.1	77.7	82	10	2CuE18	10Cs	0	0	2	ENE10				
	0457	745	81.7	77.2	81	10	2CuE18	1As 160	10Cs	0	3	ENE10	0404-0413			
	0559	740	81.7	77.3	82	10	2CuE18	1As 160	10Cs	0	3	ENE15				
	0655	745	81.7	77.3	82	10	2CuE18	1As 160	10Cs	0	3	NE10				
	0755	750	82.0	80.0	91	10	2CuE18	1As 160	10Cs	0	3	NE9	0710-0715			
	0855	760	82.0	80.0	91	10	2CuE18	1As 160	10Cs	0	3	NE8				
	0956	770	84.0	80.0	84	10	2CuE18	3As 160	10Cs	0	6	N8				
	1055	775	84.0	81.0	88	10	2CuE18	3As 160	10Cs	0	6	NNE7				
	1155	765	81.1	78.0	88	10	1CuE18	2AcE140	10Cs	0	5	NNE6				
	1255	760	82.0	80.0	91	10	1CuE18	2AcE140	10Cs	0	5	E9				
	1355	745	83.0	79.0	84	10	1CuE18	2AcE140	10Cs	0	5	ESE8				
	1455	725	84.0	79.0	80	10	1CuE18	2AcE140	10Cs	0	5	E10				
	1559	710	88.0	80.0	71	10	2CuE18	10Cs	0	0	4	E10				
	1659	710	87.5	80.0	72	10	2CuE18	10Cs	0	0	4	E11				
	1756	700	87.0	77.0	64	10	2CuE18	10Cs	0	0	3	E3				
	1859	705	84.0	77.0	73	10	2CuE18	10Cs	0	0	3	ENE14				
	1956	720	83.0	78.0	80	10	2CuE18	10Cs	0	0	3	ENE13				
	2056	735	83.0	77.0	76	10	2CuE18	10Cs	0	0	3	ENE11				
	2158	750	82.5	78.3	83	10	2CuE18	10Cs	0	0	3	ENE10				
	2256	755	82.1	77.7	82	10	2CuE18	10Cs	0	0	3	NE10				
	2358	765	82.1	77.7	82	10	2CuE18	10Cs	0	0	3	ENE12		88	82	0.32
8/31	0055	755	82.1	77.7	82	10	3CuE18	10Cs	0	0	3	E14				
	0157	745	82.5	78.3	83	10	3CuE18	10Cs	0	0	3	E10				
	0257	730	81.7	77.3	82	10	2CuE18	10Cs	0	0	2	E9				
	0358	710	81.7	77.3	82	10	2CuE18	10Cs	0	0	2	E12				
	0455	710	81.5	77.3	83	10	2CuE18	10Cs	0	0	2	E13				
	0558	695	81.3	77.0	82	10	3CuE18	10Cs	0	0	3	E13				
	0659	700	83.0	77.0	76	10	3CuE18	10Cs	0	0	3	E18				
	0756	705	83.0	77.0	76	10	3CuE18	10Cs	0	0	3	E14				
	0856	720	84.0	80.0	84	10	2CuE18	10Cs	0	0	2	E15				
	0958	725	85.5	80.0	79	10	1CuE18	10Cs	0	0	2	E12				
	1056	725	87.0	80.5	75	10	1CuE18	2AcE160	10Cs	0	4	E14				
	1158	730	87.0	81.0	77	10	1CuE18	1AcE160	10Cs	0	3	E12				
	1259	730	87.0	80.8	76	10	3CuE18	1AcE160	10Cs	0	5	E16				
	1355	720	86.5	80.5	77	10	3CuE18	1AcE160	10Cs	0	4	E15				
	1458	675	87.0	80.5	75	10	4CuE18	10Cs	0	0	4	E14	1448-1457			
	1557	680	86.5	80.0	75	10	2CuE18	10Cs	0	0	3	E8				
	1658	680	86.3	80.0	76	10	1CuE18	10Cs	0	0	3	E10				
	1756	680	86.3	80.0	76	10	1CuE18	10Cs	0	0	3	E11				

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HOURLY OBSERVATIONS AND DAILY SUMMARY AUGUST 18 - SEPTEMBER 1, 1957

TABLE 4 (Concluded)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
8/31	1859	675	84.8	77.0	70	10	1CuE18	10Cs	0	0	4	E10				
	1958	715	83.3	77.0	75	10	1CuE18	10Cs	0	0	3	E10				
	2055	735	83.3	78.5	81	10	1CuE18	10Cs	0	0	3	E10				
	2156	755	83.0	79.3	85	10	2CuE18	10Cs	0	0	3	E14	2123-2129			
	2255	770	83.0	80.0	88	10	2CuE18	10Cs	0	0	3	E14				
	2355	785	83.0	79.0	84	10	2CuE18	10Cs	0	0	3	E11	2318-2321	87	81	0.06
9/1	0058	780	82.2	77.6	81	10	4CuE18	10Cs	0	0	4	E12				
	0156	765	82.0	77.5	81	10	3CuE18	10Cs	0	0	5	SE11				
	0257	750	82.0	77.5	81	10	3CuE18	10Cs	0	0	3	SE15				
	0359	745	81.8	77.1	82	10	3CuE18	10Cs	0	0	3	S8				
	0457	745	81.5	77.5	83	10	3CuE18	10Cs	0	0	3	SE12	0409-0425			
	0559	755	81.5	77.5	83	10	3CuE18	10Cs	0	0	3	SE17				
	0656	765	81.8	77.1	82	10	3CuE18	10Cs	0	0	3	SE14				
	0759	775	82.5	78.4	84	10	1CuE18	4AsE120	10Cs	0	3	SE12				
	0856	790	83.9	78.4	78	10	2CuE18	5AsE120	10Cs	0	5	SE12				
	0955	810	84.5	80.0	82	10	3CuE18	5AsE120	10Cs	0	5	SE10				
	1056	815	85.9	80.6	79	10	0CuE18	10Cs	0	0	5	ESE10				
	1157	800	86.3	80.2	77	10	10Ci	0	0	0	3	SE10				
	1255	795	86.2	80.2	77	8	0CuE16	8Ci	0	0	6	ESE12				
	1355	760	87.6	80.3	74	8	8Ci	0	0	0	6	ESE11				
	1457	745	86.5	80.5	77	8	8Ci	0	0	0	6	ESE10				
	1559	735	89.0	80.6	70	5	1ScE50	4Ci	0	0	6	ESE9				
	1657	735	87.3	78.6	68	8	1ScE50	7Ci	0	0	3	E11				
	1758	740	87.1	79.5	72	7	1CuE18	1ScE50	0	0	6	E12				
	1857	755	84.0	78.1	76	10	2CuE18	1ScE50	5Ci	0	6	E10				
	1955	790	84.3	78.5	76	10	2CuE18	1AcE140	10Cs	0	3	E10				
	2058	795	84.3	78.8	78	10	2CuE18	1AcE140	10Cs	0	4	E11				
	2159	820	83.7	78.2	78	10	2CuE18	1AcE140	10Cs	0	4	E10				
	2257	820	82.9	77.7	80	10	2CuE18	1AcE140	10Cs	0	4	ESE11				
	2358	830	82.6	77.5	80	10	2CuE18	1AcE140	10Cs	0	3	ESE11		89	82	0.02

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
8/18	0000	1008	Surface	28.5	23.4	74	60 - 2
		1000	75	28.1	M	M	60 - 2
		850	1492	17.6	15.6	88	100 - 2
		700	3137	10.4	-1.3	44	110 - 3
		600	4405	2.8	-1.6	79	100 - 7
		500	5860	-6.0	-9.8	74	110 - 8
		400	7576	-15.7	-25.2	44	110 - 5
		300	9680	-30.6	MB	(20)	210 - 6
		200	12414	-55.0	----	--	310 - 2
		150	14188	-67.9	----	--	240 - 3
		100	16554	-75.8	----	--	190 - 6
	1200	1009	Surface	27.5	26.1	92	130 - 5
		1000	85	27.3	25.8	92	130 - 5
		850	1506	18.8	13.0	69	130 - 6
		700	3147	10.0	2.6	60	110 - 6
		600	4413	2.9	-3.9	61	100 - 6
		500	5867	-5.3	-13.6	52	90 - 6
		400	7586	-16.4	-29.2	32	80 - 4
		300	9684	-31.6	MB	(20)	290 - 5
		200	12413	-53.3	----	--	220 - 7
		150	14206	-66.4	----	--	230 - 16
		100	16577	-78.2	----	--	260 - 10
8/19	0000	1010	Surface	28.0	21.8	69	80 - 2
		1000	94	27.2	21.7	72	90 - 3
		850	1510	17.8	13.6	76	100 - 5
		700	3150	9.4	3.8	68	90 - 9
		600	4412	1.9	-2.8	71	90 - 7
		500	5862	-6.5	-12.4	63	90 - 10
		400	7574	-16.5	-29.3	32	130 - 5
		300	9672	-31.8	MB	(20)	200 - 5
		200	12409	-57.2	----	--	250 - 11
		150	14196	-67.9	----	--	230 - 24
		100	16543	-79.3	----	--	260 - 11
	1200	1009	Surface	28.0	22.1	70	80 - 5
		1000	85	27.6	22.8	75	90 - 5
		850	1497	18.0	13.4	74	90 - 7
		700	3138	10.4	-8.2	26	90 - 10
		600	4406	3.3	-12.8	30	90 - 10
		500	5862	-6.0	-15.6	47	100 - 8
		400	7574	-16.8	-30.2	30	110 - 5
		300	9672	-31.3	MB	(20)	190 - 7
		200	12397	-55.0	----	--	210 - 6
		150	14177	-68.5	----	--	220 - 19
		100	16517	-79.3	----	--	270 - 8
8/20	0000	1009	Surface	27.4	22.6	75	80 - 5
		1000	85	27.1	22.8	77	80 - 6
		850	1499	17.7	7.7	52	70 - 8
		700	3138	10.2	-6.5	30	80 - 13
		600	4409	3.8	-14.9	24	100 - 10
		500	5863	-6.1	-16.7	43	80 - 7
		400	7582	-15.7	-22.5	32	110 - 5
		300	9685	-31.5	-42.2	34	180 - 5
		200	12414	-54.8	----	--	220 - 6
		150	14196	-66.9	----	--	250 - 16
		100	16542	-83.3	----	--	250 - 14

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
8/20	1200	1010	Surface	27.5	22.5	74	90 - 8
		1000	94	26.8	M	M	90 - 8
		850	1507	17.8	14.1	79	100 - 7
		700	3153	10.9	-3.2	37	120 - 6
		600	4423	4.1	-11.9	30	130 - 6
		500	5884	-4.9	-18.7	33	130 - 7
		400	7609	-14.2	M	M	80 - 5
		300	9721	-30.2	M	M	120 - 9
		200	12467	-53.1	----	--	100 - 7
		150	14266	-66.1	----	--	60 - 8
		100	16630	-78.4	----	--	70 - 10
8/21	0000	1010	Surface	28.5	23.9	76	80 - 4
		1000	94	28.4	24.4	79	80 - 5
		850	1519	18.1	16.3	89	110 - 7
		700	3160	9.8	7.6	86	100 - 11
		600	4427	2.9	-1.0	75	100 - 11
		500	5884	-4.8	-11.6	59	100 - 10
		400	7603	-15.6	MB	(17)	80 - 7
		300	9707	-30.5	MB	(20)	90 - 2
		200	12447	-54.1	----	--	270 - 7
		150	14231	-67.9	----	--	280 - 12
		100	16575	-81.0	----	--	350 - 6
	1200	1010	Surface	27.5	22.3	73	120 - 8
		1000	93	26.5	M	M	170 - 6
		850	1510	19.0	14.1	73	160 - 3
		700	3158	11.0	3.1	58	120 - 3
		600	4427	3.1	-5.8	52	120 - 8
		500	5886	-4.9	-14.0	49	120 - 8
		400	7605	-16.2	-24.2	50	120 - 6
		300	9707	-31.4	-36.2	63	120 - 9
		200	12436	-54.7	----	--	290 - 6
		150	14215	-69.0	----	--	290 - 12
		100	16583	-75.1	----	--	80 - 7
8/22	0000	1010	Surface	27.0	22.9	78	180 - 5
		1000	94	26.9	22.7	78	185 - 4
		850	1510	17.9	14.6	81	140 - 3
		700	3149	8.6	5.1	79	105 - 6
		600	4409	0.8	-2.9	81	100 - 6
		500	5853	-7.5	-12.8	66	90 - 7
		400	7565	-16.7	-21.8	64	90 - 7
		300	9668	-30.9	MB	(20)	50 - 7
		200	12402	-54.7	----	--	50 - 7
		150	14191	-69.8	----	--	360 - 10
		100	16512	-77.3	----	--	260 - 11
	1200	1009	Surface	27.1	21.6	72	30 - 7
		1000	84	26.1	21.6	76	40 - 5
		850	1500	18.9	15.8	82	80 - 2
		700	3142	9.8	5.0	72	10 - 2
		600	4403	1.9	-0.9	90	340 - 3
		500	5856	-6.3	-9.0	81	30 - 9
		400	7575	-15.7	-20.3	68	10 - 7
		300	9677	-31.8	-40.5	42	90 - 6
		200	12409	-54.0	----	--	340 - 6
		150	14194	-67.0	----	--	350 - 17
		100	16565	-77.3	----	--	210 - 5

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
8/23	0000	1009	Surface	27.5	22.9	76	60 - 5
		1000	85	27.2	22.6	76	60 - 5
		850	1501	17.8	14.6	82	70 - 9
		700	3140	8.6	5.0	78	230 - 6
		600	4399	1.2	-0.6	88	190 - 4
		500	5851	-5.4	-7.4	86	130 - 3
		400	7570	-15.8	-21.4	62	120 - 3
		300	9668	-31.9	-39.9	45	180 - 4
		200	12399	-55.0	----	--	330 - 3
		150	14178	-68.3	----	--	300 - 5
		100	16534	-76.8	----	--	270 - 3
	1200	1007	Surface	28.5	23.0	72	70 - 7
		1000	68	27.9	M	M	70 - 7
		850	1484	19.2	13.4	69	100 - 11
		700	3131	10.7	5.4	69	100 - 5
		600	4401	3.6	-0.9	72	160 - 7
		500	5860	-4.9	-10.6	64	180 - 10
		400	7502	-15.6	-22.4	56	220 - 9
		300	9684	-30.4	-39.7	40	240 - 6
		200	12420	-53.7	----	--	230 - 9
		150	14207	-67.2	----	--	260 - 3
		100	16584	-77.1	----	--	100 - 4
8/24	0000	1009	Surface	29.0	24.8	78	140 - 6
		1000	85	28.6	24.6	79	140 - 6
		850	1503	17.0	13.2	79	160 - 10
		700	3139	9.1	3.8	69	140 - 10
		600	4398	1.7	-3.4	70	150 - 8
		500	5850	-5.2	-15.9	43	180 - 9
		400	7562	-16.1	-28.3	34	120 - 10
		300	9655	-31.9	-38.9	50	220 - 6
		200	12377	-56.0	----	--	240 - 4
		150	14139	-70.5	----	--	260 - 8
		100	16476	-81.5	----	--	200 - 10
	1200	1010	Surface	27.5	21.6	70	170 - 3
		1000	94	26.8	M	M	150 - 3
		850	1509	18.1	11.8	67	130 - 4
		700	3149	9.1	3.1	66	150 - 5
		600	4416	2.2	-2.9	69	120 - 8
		500	5869	-5.2	-17.0	39	130 - 8
		400	7589	-15.7	-25.2	44	130 - 10
		300	9693	-30.1	-40.5	36	140 - 4
		200	12444	-52.7	----	--	10 - 5
		150	14234	-68.2	----	--	340 - 6
		100	16608	-79.0	----	--	120 - 5
8/25	0000	1010	Surface	28.5	23.4	74	90 - 6
		1000	94	28.2	23.1	74	90 - 6
		850	1518	19.4	12.6	65	80 - 4
		700	3170	12.1	-5.0	30	90 - 7
		600	4442	3.3	-5.2	54	90 - 7
		500	5898	-5.7	-17.2	40	80 - 8
		400	7618	-15.5	-29.4	29	110 - 6
		300	9719	-30.8	MB	(20)	90 - 4
		200	12468	-53.4	----	--	90 - 2
		150	14253	-68.3	----	--	140 - 1
		100	16605	-80.6	----	--	270 - 5

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
8/25	1200	1010	Surface	28.0	20.5	64	100 - 3
		1000	94	27.8	20.0	64	100 - 3
		850	1514	18.4	9.4	56	100 - 5
		700	3154	9.7	5.1	73	110 - 9
		600	4419	2.8	-4.2	60	90 - 10
		500	5875	-5.0	-17.4	37	80 - 9
		400	7596	-14.1	MB	(16)	60 - 9
		300	9702	-31.0	MB	(20)	40 - 7
		200	12444	-52.8	----	--	20 - 6
		150	14235	-68.0	----	--	270 - 10
		100	16576	-78.0	----	--	40 - 12
8/26	0000	1009	Surface	28.0	22.0	72	30 - 2
		1000	85	27.0	22.0	74	30 - 3
		850	1502	19.0	17.0	88	90 - 3
		700	3153	12.0	6.1	67	90 - 4
		600	4425	3.5	-0.2	77	90 - 3
		500	5883	-5.0	-16.3	41	90 - 3
		400	7600	-16.6	-19.6	78	70 - 4
		300	9702	-30.1	-37.2	50	70 - 8
		200	12445	-53.7	----	--	10 - 8
		150	14226	-68.9	----	--	340 - 9
		100	16574	-77.6	----	--	70 - 8
	1200	1008	Surface	27.0	19.0	62	110 - 3
		1000	75	26.7	19.3	69	90 - 3
		850	1490	17.6	13.9	79	110 - 6
		700	3128	2.7	-2.8	66	100 - 5
		600	4387	0.9	-3.5	72	120 - 7
		500	5833	-6.5	-7.3	M	M - M
		400	7545	-16.2	-32.0	24	M - M
		300	9646	-31.5	MB	(20)	M - M
		200	12384	-53.7	----	--	M - M
		150	14167	-69.0	----	--	M - M
		100	16493	-78.5	----	--	M - M
8/27	0000	1009	Surface	27.0	21.6	72	100 - 5
		1000	84	26.5	21.7	75	100 - 5
		850	1497	17.4	13.9	80	100 - 8
		700	3132	8.9	3.6	69	100 - 6
		600	4392	1.3	-3.3	72	90 - 7
		500	5843	-5.1	-19.6	31	140 - 4
		400	7558	-16.2	-25.6	44	90 - 2
		300	9653	-31.5	-40.0	43	30 - 4
		200	12378	-54.1	----	--	360 - 12
		150	14154	-69.3	----	--	350 - 14
		100	16473	-79.5	----	--	10 - 7
	1200	1008	Surface	27.0	25.6	92	110 - 7
		1000	76	26.6	M	M	110 - 8
		850	1486	19.3	M	M	140 - 2
		700	3124	9.0	M	M	130 - 7
		600	4384	2.1	M	M	130 - 7
		500	5837	-7.3	M	M	110 - 2
		400	7540	-17.3	M	M	30 - 5
		300	9637	-31.1	M	M	10 - 5
		200	12379	-54.2	----	--	330 - 15
		150	14161	-68.9	----	--	10 - 9
		100	16513	-76.3	----	--	30 - 7

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
8/28	0000	1009	Surface	28.7	22.8	70	120 - 5
		1000	85	27.9	23.1	75	120 - 5
		850	1501	17.9	14.9	83	150 - 4
		700	3141	8.8	-1.3	49	160 - 5
		600	4400	1.1	-3.3	72	160 - 6
		500	5848	-6.2	-14.2	53	130 - 7
		400	7563	-16.9	-26.8	42	80 - 8
		300	9656	-32.6	-37.6	61	30 - 8
		200	12380	-55.2	----	--	10 - 8
		150	14154	-69.0	----	--	360 - 21
		100	16504	-74.0	----	--	20 - 2
	1200	1010	Surface	28.0	22.1	70	180 - 3
		1000	94	27.2	22.1	74	170 - 3
		850	1517	18.8	15.0	78	170 - 3
		700	3761	9.7	2.8	62	150 - 5
		600	4424	1.8	-2.4	73	160 - 6
		500	5875	-6.2	-20.2	32	150 - 7
		400	7589	-16.5	-22.6	59	120 - 6
		300	9686	-31.3	-37.2	56	100 - 11
		200	12425	-54.0	----	--	40 - 16
		150	14204	-69.4	----	--	30 - 18
		100	16566	-74.1	----	--	30 - 5
8/29	0000	1010	Surface	27.5	21.8	71	70 - 6
		1000	94	27.0	22.5	76	70 - 6
		850	1510	18.8	13.9	73	70 - 5
		700	3155	10.0	4.7	69	100 - 2
		600	4423	2.9	-5.7	53	110 - 2
		500	5876	-6.2	-11.8	64	180 - 2
		400	7587	-17.0	-23.4	57	200 - 5
		300	9686	-30.8	-35.3	65	110 - 11
		200	12424	-55.4	----	--	60 - 14
		150	14192	-70.1	----	--	20 - 14
		100	16555	-76.8	----	--	90 - 9
	1200	1010	Surface	28.5	23.0	72	100 - 4
		1000	94	27.8	22.8	74	90 - 5
		850	1516	19.3	13.5	69	80 - 5
		700	3166	10.6	2.5	57	70 - 4
		600	4430	2.1	-3.8	65	90 - 2
		500	5898	-6.2	-11.9	64	50 - 2
		400	7593	-15.4	-28.1	33	360 - 3
		300	9699	-30.4	-41.0	35	90 - 4
		200	12447	-53.2	----	--	60 - 8
		150	14236	-67.5	----	--	110 - 6
		100	16605	-76.0	----	--	340 - 4
8/30	0000	1009	Surface	28.0	23.6	77	60 - 8
		1000	85	27.6	23.7	79	60 - 8
		850	1509	18.8	14.7	77	60 - 10
		700	3153	9.3	6.6	83	60 - 7
		600	4421	2.9	-1.3	74	50 - 2
		500	5874	-6.0	-10.9	68	350 - 2
		400	7593	-15.5	-23.7	52	20 - 5
		300	9696	-31.1	MB	(20)	20 - 2
		200	12428	-54.3	----	--	40 - 3
		150	14210	-68.6	----	--	200 - 9
		100	16567	-78.4	----	--	80 - 8

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
8/30	1200	1008	Surface	27.5	23.7	80	100 - 4
		1000	76	27.1	23.8	82	100 - 4
		850	1498	18.3	12.5	70	110 - 6
		700	3140	10.2	2.7	60	110 - 9
		600	4406	2.4	-5.9	54	100 - 8
		500	5859	-4.8	-12.6	54	160 - 2
		400	7582	-15.4	-20.3	65	310 - 3
		300	9690	-31.0	MB	(20)	290 - 7
		200	12423	-53.5	----	--	220 - 10
		150	14216	-66.1	----	--	240 - 6
		100	16593	-79.5	----	--	70 - 5
8/31	0000	1008	Surface	28.0	23.4	76	60 - 6
		1000	76	27.2	22.8	77	70 - 6
		850	1496	18.6	16.2	86	80 - 3
		700	3142	10.7	3.4	61	80 - 3
		600	4413	2.9	-2.0	70	80 - 8
		500	5870	-5.8	-10.3	70	90 - 3
		400	7584	-16.5	-22.5	60	150 - 3
		300	9679	-31.9	-41.5	38	90 - 7
		200	12409	-53.8	----	--	190 - 11
		150	14192	-68.0	----	--	190 - 14
		100	16565	-77.4	----	--	30 - 3
	1200	1007	Surface	28.6	23.1	72	80 - 6
		1000	68	28.0	22.8	73	90 - 7
		850	1494	19.6	15.6	78	90 - 7
		700	3146	11.1	2.4	59	90 - 7
		600	4417	3.1	-1.8	72	110 - 6
		500	5873	-5.8	-9.2	77	120 - 6
		400	7594	-15.6	-21.9	58	180 - 6
		300	9698	-31.6	-38.2	52	180 - 10
		200	12434	-53.8	----	--	180 - 15
		150	14231	-66.1	----	--	190 - 15
		100	16608	-75.0	----	--	110 - 10
9/1	0000	1008	Surface	26.5	21.9	76	100 - 7
		1000	75	25.8	21.6	78	110 - 7
		850	1500	19.1	17.6	91	120 - 9
		700	3148	10.6	4.7	67	90 - 9
		600	4415	2.8	-5.2	56	100 - 10
		500	5817	-5.2	-13.9	50	100 - 8
		400	7592	-14.8	-28.4	30	110 - 8
		300	9691	-31.3	MB	(20)	130 - 9
		200	12426	-52.7	----	--	180 - 12
		150	14215	-67.7	----	--	180 - 12
		100	16568	-82.4	----	--	130 - 6
	1300	1009	Surface	27.6	22.4	73	130 - 5
		1000	85	27.6	22.6	74	130 - 6
		850	1510	19.4	15.5	78	150 - 6
		700	3157	10.1	4.7	69	120 - 10
		600	4426	3.8	-4.7	54	110 - 10
		500	5889	-3.9	-10.7	59	100 - 13
		400	7620	-14.9	-20.7	61	110 - 9
		300	9731	-29.8	-36.5	52	170 - 5
		200	12485	-52.3	----	--	110 - 5
		150	14294	-66.3	----	--	90 - 6
		100	16635	-81.3	----	--	90 - 11

PLACE: BRUCE

THREE-HOURLY OBSERVATIONS, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 6

Date	Time	TT	TT_w	T_xT_x	T_nT_n	RR_L	RR_O	N	C_{LMH}	FF_3	DDFF	REMARKS
8/18	1200	89.0	--	----	----	0	0	6	Cu,Sc,Ci...	--	SE	
	1500	--	--	----	----	0	0	8	Cu,Sc,Ac,Ci	4	SE	1500 few drops of rain fell.
	1800	--	--	----	----	T	T	8	Thick Cu;Sc	2	SE	1700-1710 light shwr, also heavy squalls 3-5
	2100	--	--	----	----	0	0	1	....	1	E	miles N and E.
8/19	0000	82.0	--	94.0	80.0	0	0	1	....	4	NE	0000 clear overhead - clouds on horizon.
	0300	--	--	----	----	0	0	1	Cu.........	4	NE	
	0600	--	--	----	----	0	0	4	Cu.........	4	E	
	0900	--	--	----	----	0	0	4	Cu.........	5	E	
	1200	88.5	80.5	88.5	80.0	0	0	2	Cu.........	6	E gentle	
	1500	--	--	----	----	0	0	4	Cu.........	8	E gentle	
	1800	--	--	----	----	0	0	4	Cu,Cb......	8	E gentle	
	2100	--	---	----	----	0	0	-	....	8	E	
8/20	0000	82.5	77.0	90.5	82.5	0	0	Clear?	....	10	E	
	0300	--	--	----	----	0	0	-	....	11	E	
	0600	--	--	----	----	0	0	-	....	6	E	
	0900	85.0	77.5	----	----	0	0	-	Cu.........	9	E	
	1200	89.0	80.0	89.0	80.0	0	0	4	Cu,Ci......	9	NE moderate	1200 towering Cu on horizon.
	1500	91.0	81.0	----	----	0	0	2	Cu,Ac,Ci...	8	NE	
	1800	86.0	79.0	----	----	0	0	3	Sc,Ac......	6	NE light	
	2100	83.0	78.0	----	----	0	0	2	....	5	NE light	2300 fresh SE wind. 2315 light shwrs.
8/21	0000	80.0	77.0	91.0	80.0	0.02	0.03	5	....	5	NE	0000 dark clouds to SE.
	0300	79.0	77.0	----	----	0.02	0.01	10	....	8	S moderate	0300 steady light shwrs.
	0600	79.0	76.0	----	----	0.07	0.09	10	....	4	SE light	
	0900	82.0	77.0	----	----	0	0	10	Ac,Ci......	4	S moderate	
	1200	89.5	80.5	89.5	77.5	0	0	4	Cu,Sc,As, Ac,Ci	8	S fresh	
	1500	--	---	----	----	0	0	7	Cu,Ci......	6	S	
	1800	--	--	----	----	0	0	4	Cu,Ci......	4	S	
	2100	--	--	----	----	0	0	-	....	3	S gentle	
8/22	0000	81.0	77.0	93.0	79.5	0	0	-	....	2	Calm	0200 rain began.
	0300	--	--	----	----	0.04	0.04	-	....	1	---	0300 light rain at time of obs.
	0600	--	---	----	----	0.01	0.02	-	Cu,Sc,Ci...	2	S	
	0900	--	--	----	----	0	0	9	Cu,Sc......	2	SE	
	1200	83.0	77.5	83.0	77.5	0.25	0.28	10	Cu,Sc......	5	Calm	1100 rain ended.
	1500	--	--	----	----	T	T	10	Cu,Cb,Ac...	7	NE	
	1800	--	--	----	----	0	0	10	Cu,Sc......	8	E	
	2100	--	--	----	----	0	0	10	....	10	NE light	
8/23	0000	81.5	78.0	86.0	81.5	0	0	10	....	11	E moderate	0000 few drops of rain.
	0300	--	--	----	----	0	0	10	....	8	E light	
	0600	--	--	----	----	0.19	0.19	10	....	9	SE	0430-0545 light rain. 0600 light shwrs.
	0900	--	--	----	----	T	0.01	9	Sc,Ac,Ci...	9	NE	0830 light shower.
	1200	85.5	80.5	85.5	78.0	0	T	7	2Cu;5Ci.....	11	E 5-10	
	1500	--	--	----	----	0.01	0.01	9	4Cu;2Cb;3Ci.	9	E 5-10	1500-1505 rain with ESE wind 10-15 kts.
	1800	--	--	----	----	0	0	10	8Cu;2Ac&Ci..	11	SE 10-15	followed by E 0-5 kts. 1800 overcast.
	2100	--	--	----	----	0	0	-	....	11	SE 10-15	

PLACE: BRUCE

THREE-HOURLY OBSERVATIONS, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 6 (Continued)

Date and Time		TT	TT_w	T_xT_x	T_nT_n	RR_L	RR_O	N	C_{LMH}	FF_3	DDFF	REMARKS
8/24	0000	82.5	77.5	91.5	82.5	0	0	-	....	10	SE 10-15	
	0300	--	--	----	----	0.04	0.04	-	....	10	SE 0-5	
	0600	--	--	----	----	0	0	4	2Cu;2Ci.....	10	SE 5-10	
	0900	--	--	----	----	0	0	7	5Cu;2Ci.....	8	SE 5-10	
	1200	93.0	82.0	93.0	79.0	0	0	7	4Cu;4Ci.....	4	E 8-10	
	1500	91.0	81.5	----	----	0	0	7	3Cu;2Ac;7Ci.	5	SE 4-6	1500 towering Cu to the East.
	1800	87.0	80.0	----	----	0	0	8	2Cu;8Ci.....	5	E light and variable	
	2100	82.0	77.5	----	----	0	0	5	5Ci.........	5	E 8-10	
8/25	0000	81.5	77.5	93.0	81.5	0	0	3	3Ci.........	7	E 8-10	
	0300	81.5	76.5	----	----	0	0	3	3Ci.........	8	E 10-15	
	0600	81.0	76.5	----	----	0	0	3	1Cu;2Ci.....	6	SE 6-8	
	0900	85.5	79.0	----	----	0	0	10	2Cu;2Ac;10Cs	5	SE 8-10	
	1200	93.0	81.5	93.0	81.0	0	0	9	2Cu;7Sc.....	5	E 5-10	
	1500	88.5	79.0	----	----	0	0	9	2Cu;1Ac;6Ci.	3	E 0-2	
	1800	88.5	77.5	----	----	0	0	9	2Cu;3Ac;4Ci.	3	Calm	1730 calm began.
	2100	83.0	77.0	----	----	0	0	-	....	1	Calm	2120-2125 light shwr.
8/26	0000	82.0	77.5	93.0	82.0	T	T	-	....	1	Calm	
	0300	80.0	77.0	----	----	0	0	-	....	3	Calm	
	0600	81.0	78.0	----	----	0	0	5	.Cu.........	3	SE 0-2	0645-0700 rain shwr.
	0900	82.5	79.5	----	----	0.03	0.04	9	.Cu&Sc......	4	SE 0-2	0900 shwr over Elmer and lagoon, partial
	1200	88.0	81.5	88.0	80.0	0.01	T	6	4Cu;2Ac;3Ci.	5	SE 10-12	rainbow to west. 0918 shwr began. 0923
	1500	94.0	82.0	----	----	T	0.01	6	3Cu;6Ci.....	6	SE 8-10	shwr stopped. 1155 rain shwr began. 1205
	1800	85.0	79.5	----	----	0.04	0.01	9	4Cu;4Ac;2Ci.	4	E 4-6	stopped. 1200 towering Cu all Quads. 1700
	2100	82.0	78.5	----	----	0	0	-	....	5	E 8-10	rain shwr began. 1710 stopped. 1730 rain
8/27	0000	82.0	77.5	94.0	82.0	0	0	-	....	9	SE 10-15	shwr began. 1740 stopped. 1800 towering
	0300	81.0	78.0	----	----	0.02	T	-	....	9	E 10-15	Cu all Quads. 0250 rain shwr began. 0255
	0600	81.5	78.0	----	----	0	T	5	3Cu;3Ci.....	10	E 10-15	stopped. 0300 towering Cu all Quads. 0600
	0900	84.0	79.5	----	----	0	0	6	4Cu;2Ac;2Ci.	6	SE 8-12	towering Cu NE. 0900 towering Cu all Quads
	1200	90.0	81.0	90.0	81.0	0	0	3	2Cu;1Sc.....	13	E 15	and rain shwrs to S.
	1500	93.5	82.0	----	----	0	0	5	4Cu;1Sc.....	11	E 20	
	1800	87.0	80.0	----	----	0	0	8	4Cu;4Ci.....	10	E 15	
	2100	82.5	78.0	----	----	0	0	-	....	8	SE 12	
8/28	0000	82.0	78.0	94.0	82.0	0	0	-	....	8	E 10	
	0300	81.5	77.5	----	----	T	T	-	....	7	SE 20	
	0600	81.1	77.5	----	----	0	0	2	....	6	SE 10	
	0900	86.0	79.0	----	----	0	0	8	....	4	S 10	0900 hazy sun.
	1200	89.0	80.0	89.0	81.0	0	0	10	2Cu;6Ac;6Ci.	3	Calm	1200 very dark horizon to east.
	1500	85.5	78.5	----	----	0	0	10	3Cu;10Ac....	2	E 1-2	1500 very dark horizon to SE.
	1800	82.0	78.5	----	----	0	0	10	2Cu;10Ac....	6	E 6-8	
	2100	81.0	77.0	----	----	0	0	-	....	9	E 8-10	
8/29	0000	80.5	77.0	90.5	80.5	0	0	-	....	10	E 6-8	
	0300	81.0	77.5	----	----	0	0	-	....	8	E 6-8	
	0600	81.5	78.0	----	----	0	0	7	5Cu;5Ci.....	10	E 4-6	0600 shwrs in sight in all quadrants. 0803
	0900	86.0	79.5	----	----	T	T	5	2Cu;4Ci.....	8	E 3-5	light shwr began. 0807 stopped. 0900
	1200	88.5	80.0	88.5	80.5	0	0	3	.Cu.........	6	E 0-5	cirrus very thin. 1200 wind variable in spd.

PLACE: BRUCE

THREE-HOURLY OBSERVATIONS, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 6
(Concluded)

Date	Time	TT	TT_w	T_xT_x	T_nT_n	RR_L	RR_O	N	C_{LMH}	FF_3	DDFF	REMARKS
8/29	1500	89.0	79.5	----	----	0	0	4	2Cu&Cb;2Ci..	9	E 3-8	1500 wind speed variable; towering Cu to W.
	1800	82.5	78.0	----	----	0.03	0.03	10	8Cu;2Ci.....	11	E 5-8	1632 few drops rain. 1720-1728 light shwr.
	2100	82.5	78.5	----	----	0.01	0.01	5	Cu.........	11	E 5-10	1800 wind speed variable; towering Cu to W.
8/30	0000	82.5	78.5	89.0	82.5	0	0	-	....	12	E 8-10	S half of lagoon covered with shwrs; shwrs
	0300	82.0	78.0	----	----	0	0	-	....	8	E 5	to seaward SSE and E of Bruce. 1828-1853
	0600	82.0	77.5	----	----	0	0	2	Cu.........	8	E 2-5	very light shwr. 1912-1919 very light shwr.
	0900	84.0	79.0	----	----	T	T	9	Cu.........	6	Calm	2100 gusty winds. 0851-0854 light shwr.
	1200	86.0	80.0	86.0	82.0	0.36	0.39	4	2Cu;2Ci.....	3	SE 0-2	0900 rain shwr. Rain seaward in SE quadrant;
	1500	91.0	82.0	----	----	0	0	3	2Cu;1Ci.....	4	E 3-5	rainbow to W. 0935 9/10 sky cover -5Sc;3Cu;
	1800	86.5	80.0	----	----	0	0	7	7Cu.........	6	E 0-5	1Ac. 0950-1023 rain shwr. 1830-1845 rain
	2100	81.5	78.0	----	----	0.27	0.28	-	....	8	E 5-10	shwr. Wind E 15-20.
8/31	0000	81.5	78.0	91.0	81.5	0	0	-	....	9	E 8-12	
	0300	82.0	78.0	----	----	0	0	-	....	9	E 8-12	
	0600	82.0	77.0	----	----	0	0	3	2Cu;1Ci.....	11	E 8-12	
	0900	84.5	79.5	----	----	0	0	6	5Cu;1Ci.....	10	E 8-12	
	1200	89.0	81.0	89.0	80.5	0	0	6	3Cu;2Ac;1Ci.	10	E 15	
	1500	91.0	83.0	----	----	0	0	6	2Cu;3Sc;1Ac.	11	E 15	
	1800	87.0	80.0	----	----	0	0	8	6Cu;2Ci.....	11	E 15	
	2100	83.0	79.0	----	----	0	0	-	....	8	E 12	2100 thin high cirrus. Halo around moon.
9/1	0000	81.0	78.0	91.0	81.0	T	T	-	....	6	E 15	2345-0045 rain shwr. 0000 showery.
	0300	80.0	78.0	----	----	0.04	0.04	-	....	11	SE 12	0345 light shwr.
	0600	81.0	78.0	----	----	0.01	0.01	6	....	10	SE 20	
	0900	85.0	79.0	----	----	0	0	9	2Cu;7Ci&Cs..	11	SE 15	0900 hazy.

PLACE: BRUCE

SPECIAL OBSERVATIONS, AUGUST, 1957

TABLE 7

DATE	LOCATION	TIME	HT. (ft.)	TT	TT_w	TT_s	REMARKS
28th	Ocean water line	1530	5	83.0	78.0		This set of observations on August 28th represents readings on a cross-BRUCE traverse along a line past the shelter and parallel to the line of wells (on old airstrip). Wind throughout was ENE, 2-3 knots.
	Edge of vegetation,ocean	1533	5	83.5	78.0		
	Opposite Well #5	1536	5	84.2	78.6		
	Opposite instrument shelter	1539	5	83.8	78.0		
	Opposite Well #4	1542	5	83.8	78.4		
	Opposite Well #4, but about 75 feet into vegetation	1546	5	84.5	78.9		
	Opposite Well #3	1550	5	83.9	77.9		
	Opposite Well #2	1553	5	83.8	77.6		
	Edge of vegetation, lagoon	1557	5	83.7	77.7		
	Lagoon water line	1600	5	83.8	77.5		
30th	Edge of water, lagoon	1208		86.0	80.0	84.6	The 1208-1241 observations are from a lagoon-ocean traverse on a line passing the shelter and parallel to the line of wells.
	Edge of water, lagoon	1210	5	86.0	79.5		
	Edge of vegetation, lagoon	1212	5	87.0	80.0		
	Edge of vegetation, lagoon	1213	1	87.0	82.0		
	Opposite Well #1	1215	5	85.5	79.5		
	Opposite Well #1	1216	1	87.0	82.0		
	Opposite Well #2	1217	5	87.5	81.0		
	Opposite Well #2	1218	1	91.0	84.0		
	Opposite Well #3	1221	5	87.0	80.5		
	Opposite Well #3	1222	1	92.5	86.5		
	Opposite Well #4	1224	5	81.0	80.5		
	Opposite Well #4	1225	1	87.5	82.0		
	Opposite instrument shelter	1227	5	86.0	80.0		
	Opposite instrument shelter	1228	1	91.0	84.0		
	Opposite Well #5	1229	5	87.5	81.0		
	Opposite Well #5	1230	1	89.5	83.5		
	Edge of vegetation, ocean	1232	5	86.0	80.0		
	Edge of vegetation, ocean	1234	1	88.0	83.5		
	Edge of water (on reef)	1241	5	85.5	82.0		
	Edge of water (on reef)	1241	1	84.0	78.5	84.6	
	15 yards to edge of ocean reef	1510	3	85.0	79.5	85.1	The 1510-1540 observations are along the same line, but from ocean to lagoon.
	Halfway in on ocean reef	1515	5	84.5	78.5		
	Edge of vegetation, ocean	1519	5	86.5	80.0		
	Edge of vegetation, ocean	1520	1	90.5	83.5		
	Opposite Well #5	1523	5	90.0	82.5		
	Opposite Well #5	1524	1	91.0	83.0		
	Opposite instrument shelter	1525	5	90.5	82.5		
	Opposite instrument shelter	1526	1	91.5	82.5		
	Opposite Well #4	1527	5	90.5	82.0		
	Opposite Well #4	1529	1	90.5	82.5		

PLACE: BRUCE

SPECIAL OBSERVATIONS, AUGUST, 1957

TABLE 7
(Concluded)

DATE	LOCATION	TIME	HT. (ft.)	TT	TT_w	TT_s	REMARKS
30th	Opposite Well #3	1530	5	89.5	81.0		
	Opposite Well #3	1531	1	91.0	82.0		
	Opposite Well #2	1532	5	90.5	81.5		
	Opposite Well #2	1533	1	91.5	82.0		
	Opposite Well #1	1534	5	89.5	81.0		
	Opposite Well #1	1535	1	90.0	82.0		
	Edge of vegetation, lagoon	1536	5	88.5	80.0		
	Edge of vegetation, lagoon	1537	1	91.0	82.0		
	Edge of lagoon	1539	5	90.5	81.5	86.0	
	Edge of lagoon	1540	1	90.5	82.5		
	Edge of lagoon	1540	5	89.0	81.0	85.3	
	Edge of water, ocean	2109	5	83.0	78.5	83.5	The 2109-2131 observations are the same traverse as above, ocean to lagoon.
	Edge of water, ocean	2110	1	83.0	79.0		
	Edge of vegetation, ocean	2112	5	83.0	78.5		
	Edge of vegetation, ocean	2113	1	82.0	79.0		
	Opposite Well #5	2115	5	84.0	82.5		
	Opposite Well #5	2115	1	84.0	82.0		
	Opposite instrument shelter	2116	5	84.0	82.0		
	Opposite instrument shelter	2117	1	83.5	82.0		
	Opposite Well #4	2120	5	82.0	79.0		
	Opposite Well #4	2121	1	82.0	79.0		
	Opposite Well #3	2122	5	82.0	78.5		
	Opposite Well #3	2123	1	81.5	78.5		
	Opposite Well #2	2124	5	82.0	78.5		
	Opposite Well #2	2125	1	81.5	79.0		
	Opposite Well #1	2126	5	82.0	78.5		
	Opposite Well #1	2127	1	81.5	78.5		
	Edge of vegetation, lagoon	2129	5	82.0	78.5		
	Edge of vegetation, lagoon	2129	1	81.5	78.5		
	Edge of lagoon water	2131	5	82.0	79.0	84.2	

PLACE: KEITH

THREE-HOURLY OBSERVATIONS, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 8

Date	Time	TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	FF_3	DDFF	REMARKS
8/18	1200	87.5	78.5	89.0	80.0	0	4	4Cu..........	--	NE	
	1500	89.0	79.0	----	----	0	7	7Cu..........	4	E	
	1800	88.5	78.0	----	----	0	4	4Cu..........	4	NE	1700 Partial rainbow, NE
	2100	82.5	75.5	----	----	0	1	1Cu..........	2	NE	
8/19	0000	82.5	77.0	90.5	82.5	0	1	1Cu..........	4	E	
	0300	82.0	76.0	----	----	0	3	2Cu;1Ac.....	5	NE	
	0600	81.5	77.5	----	----	0	8	7Cu;1Ac.....	5	NE	
	0900	86.0	79.0	----	----	0	5	5Cu..........	3	NE	
	1200	91.0	81.0	91.0	75.5	0	4	4Cu..........	7	E	
	1500	92.5	81.0	----	----	0	3	3Cu..........	11	E	
	1800	86.5	79.5	----	----	0	4	4Cu..........	11	E	
	2100	83.0	77.0	----	----	0	1	1Cu..........	12	E	
8/20	0000	82.0	77.0	92.5	82.0	0	1	1Cu..........	12	E	
	0300	81.5	77.0	----	----	0	3	2Cu;1Ci.....	11	E	
	0600	81.5	75.0	----	----	0	8	2Cu;6Ci.....	10	E	0645-0730 calm. 0800-0830 Rainbow to W. Line of
	0900	85.5	77.0	----	----	0	7	2Cu;1Ac;4Ci.	12	E	shwrs. 5-10 mi. S, moving W. 0900 Cu in SE,SW
	1200	91.0	79.0	91.0	81.0	0	6	3Cu;3Ci.....	12	E	1200 Cu well developed S to W
	1500	90.5	79.0	----	----	0	3	2Cu;1Ci.....	13	E	1500 Cu well developed in N. 1700-1900 very light
	1800	88.5	79.0	----	----	0	2	Cu..........	4	E	winds. 1800 few Ci in NW
	2100	83.0	77.0	----	----	0	2	Cu..........	8	E	
8/21	0000	82.5	77.0	91.0	82.5	0	8	Cu..........	8	E	0000 Few drops of rain
	0300	78.5	77.0	----	----	0.05	10	Sc..........	9	W	0255-0310 light shwrs. 0340-0347 light shwrs.
	0600	81.0	77.0	----	----	0.01	10	Sc..........	8	S	
	0900	83.0	77.0	----	----	T	10	6Cu;4Ci.....	7	SE	
	1200	83.0	78.0	83.0	78.0	0	9	1Cu;7Ac,As; 1Ci	10	S	
	1500	85.0	78.0	----	----	0	9	5Cu;8Ci.....	12	S	
	1800	84.0	78.0	----	----	0	8	3Cu;5Ac.....	9	SW	
	2100	82.0	77.5	----	----	0	5	1Cu;4Ci.....	8	S	
8/22	0000	82.0	78.0	85.5	82.0	0	2?	Cu..........	4	S	
	0300	80.0	76.0	----	----	0	3?	Cu..........	1	Calm	
	0600	81.0	77.5	----	----	0	9	1Cu;8As.....	2	W	0600 halo observed 45°
	0900	84.5	79.0	----	----	0	10	4Cu;4Cs; 2Ac,As	4	N to Calm	0915 beginning light shwr.
	1200	83.5	78.5	84.5	80.0	0.01	10	9Cu;Sc,Ac,Ci	6	NE under 4	9:12 from chopper en route to Keith, observed 4 shwrs. northward over lagoon. One, 5-10 miles
	1500	88.5	78.0	----	----	0	10	Ac,Ci,Cu...	7	E 8-10	across, may have extended over Janet. Other 3
	1800	83.5	78.0	----	----	0	10	6Cu;3Ac,Ci..	11	E 12-14	were much smaller -- 1 mile or so across.
	2100	83.5	77.5	----	----	0	--	....	13	E 12-15	10:18 light rain begins from edge of low cloud that
8/23	0000	81.5	78.0	88.5	81.5	0	--	....	13	E 12-14	has drifted in from east. Cloud extends northward
	0300	82.0	78.5	----	----	T	--	....	12	E 4-6	from Keith. Rain ended 1100. 0003-0030 Lt.rain.
	0600	80.0	77.0	----	----	0.10	10	Cu,Sc,Ac...	11	E 5-8	0255-0610 light to moderate rain,changing to very
	0900	82.5	79.0	----	----	T	9	Cu,As,Ci...	12	E 8-10	light rain 0610 to 0735,when rain ended.
	1200	87.0	80.0	87.0	80.0	T	9	8Cu,Sc;1Ac, Ci	16	NE 10-15	1004-1008 light shwrs. 1200 gusts to 20 knots.

PLACE: KEITH

THREE-HOURLY OBSERVATIONS, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 8 (Continued)

Date	Time	TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	FF_3	DDFF	REMARKS
8/23	1500	87.0	79.0	----	----	0	10	4Cu;5Ci;1Ac..	11	E 5-10	1700-1800 Squall line about 10 miles southwest of
	1800	83.0	79.0	----	----	0	10	2Cu;8Sc......	10	SE 10	Keith. 1800 rain in lagoon between Bruce and
	2100	81.5	77.0	----	----	0.02	10	8Cu;2Ci......	9	SE 10-15	Keith. 1803 few drops of rain. 1950 few drops of rain. 2008-2017 rain. 2100 light shwr.
8/24	0000	83.0	78.0	87.5	80.0	0	10	Sc..........	10	SE 10-15	0040 few drops of rain.
	0300	82.0	77.5	----	----	T	10	4Cu;6Ci......	9	E 5-15	0300 winds variable. 0440 rain started - stopped
	0600	81.0	77.5	----	----	0.03	10	4Cu;6Ci......	9	SE 5-10	sometime before 0600. 0745 partial rainbow
	0900	83.0	78.0	----	----	0	10	3Cu;7Ci......	9	SW 5-10	southwest of Keith. 0900 rain in lagoon N of
	1200	83.0	77.0	85.0	79.5	0.21	7	3Cu;3Sc;1Ac..	5	SE 5	Bruce-Keith line. 1040 started raining. 1100 rain
	1500	89.5	81.0	----	----	T	7	6Cu;1Sc,Ac...	4	E 5-10	slackened to light shwr. 1115-1300 intermittent
	1800	85.5	78.0	----	----	0	8	2Cu;3Ac;3Ci..	7	E 5-10	light shwrs. 1800 halo around hazy sun.
	2100	82.0	77.0	----	----	0	3	....	6	E 12	
8/25	0000	82.0	77.0	90.0	82.0	0	3	....	8	E 15	
	0300	81.5	77.0	----	----	0	3	....	9	E 15	
	0600	81.0	75.0	----	----	0	7	....	9	NE 18	
	0900	83.0	76.5	----	----	0	9	1Cu;8Ci,Cs,Ac	6	SE 10	0900 high thin Ci,Cs.
	1200	88.0	78.0	88.0	81.0	0	8	1St;7Ci......	4	E 0-5	
	1500	89.0	77.0	----	----	0	8	1Cu;1St;6Ci..	1	E 0-5	
	1800	89.0	77.5	----	----	0	8	4Cu;4Ci......	1	Calm	
	2100	81.0	76.0	----	----	0	--	....	0	Calm	2100 rain started. 2115 rain stopped.
8/26	0000	79.0	75.5	91.0	79.0	T	--	....	0	Calm	0215 wind E 15-20 kts. 0225-0235 rain. 0240 wind
	0300	81.0	75.5	----	----	T	--	....	4	E 5-10	dropped.
	0600	81.0	76.5	----	----	T	--	....	1	E 0-5	0655 sky cover 3/10;2/10 Cu 1/10 Ci. 0830 -0835
	0900	86.0	79.0	----	----	0	6	4Cu;2Ci......	3	E 0-5	rain. 0940 large Cb over lagoon to E. 1013 few
	1200	87.0	78.8	87.0	78.5	0.07	6	4Cu&Cb;2Ac; 6Ci	3	E 3-4	drops of rain. 1016 shwr commenced. 1035 shwr stopped. 1200 rain shwr over lagoon to NE.
	1500	86.5	77.5	----	----	0	6	4Cu&Cb;1Ac; 6Ci	3	E 2-3	1500 rain shwr to W over ocean.
	1800	85.0	77.0	----	----	0	9	4Cu&Cb;3Ac; 8Ci	1	Calm	1800 many shwrs in sight in all quadrants. 1910 few drops of rain.
	2100	81.0	77.0	----	----	0	--	....	2	SE 3-5	2100 heavy rain shwr commencing -- gusty wind.
8/27	0000	81.5	77.5	88.5	79.0	0.10	--	....	9	SE 6-8	2115 shwr stopped.
	0300	81.5	76.0	----	----	0	--	....	10	E 8-10	
	0600	80.5	77.0	----	----	0	3	2Cu;3Ci......	10	E 6-8	0720 shwr commenced. 0732 shwr stopped. 0750 few
	0900	82.5	78.5	----	----	0.08	7	4Cu;(Ac);6Ci.	9	E 4-6	drops of rain. 0845 very light shwr. 0910 few
	1200	86.5	80.5	86.5	78.0	0.01	8	8Cu..........	10	SE 5-10	drops of rain. 0900 many shwrs over lagoon. 1040
	1500	88.5	80.0	----	----	0	5	5Cu..........	12	SE 10-12	-1130 light shwr.
	1800	87.0	78.0	----	----	0	8	2Cu;6Ci......	11	SE 10-12	
	2100	82.5	78.0	----	----	0	--	....	8	SE 8-12	
8/28	0000	81.5	77.5	88.5	81.5	0	--	....	8	SE 8-12	
	0300	82.0	77.5	-----	----	0	--	....	7	SE 5-10	
	0600	82.0	77.0	----	----	0	3	2Cu;1Ci......	5	SE 5-10	

PLACE: KEITH

THREE-HOURLY OBSERVATIONS, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 8
(Concluded)

Date and Time		TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	FF_3	DDFF	REMARKS
8/28	0900	84.5	78.0	----	----	0	8	3Cu;5Ci......	5	S 5-10	
	1200	87.0	79.5	87.0	81.0	0	10	2Cu;10Cs.....	4	SE 3-5	
	1500	87.5	78.5	----	----	0	10	2Cu;2Ac;10Cs.	1	Calm	
	1800	83.5	77.5	----	----	0	10	3Cu;10Cs.....	6	E 8-10	
	2100	82.0	78.5	----	----	0	--	....	11	E 10-12	
8/29	0000	81.5	77.0	87.5	81.5	0	--	....	13	E 10-15	
	0300	81.0	77.0	----	----	0	--	....	10	E 8-10	
	0600	81.5	77.5	----	----	0	4	4Cu;2Ci......	12	E 8-10	
	0900	85.0	79.0	----	----	0	6	6Cu..........	7	E 4-6	
	1200	88.0	80.5	88.0	79.5	0	4	4Cu..........	9	NE 12	
	1500	89.0	80.0	----	----	0	4	2Cu;1Cb;1Cs..	15	NE 20	1705 light shwr began. 1730 rain began. 1745 rain
	1800	84.5	79.5	----	----	0.02	7	3Cu;4Sc......	12	NE 20	ended. 1815 rain began (wind gusty). 1830 rain
	2100	82.5	77.5	----	----	0.08	--	....	14	NE 20	ended. 1920 rain began. 1930 rain ended. 2030
8/30	0000	83.0	78.5	90.0	80.0	0	--	....	14	NE 20	lightning to west. 2300 lightning to north.
	0300	82.5	78.0	----	----	T	--	....	10	NE 15	
	0600	82.5	77.5	----	----	0	--	....	11	NE 12	
	0900	85.5	78.0	----	----	0	3	1Cu;1Sc;1Ci,Ac	8	NE 10	1000 rain shwr began. 1015 stopped. 1020 rain shwr
	1200	85.5	79.0	85.5	82.0	0.29	6	4Cu;2Ac;4Ci..	4	E 5-8	began. 1045 stopped. 1200 towering Cu all Quads.
	1500	87.5	80.0	----	----	0	4	2Cu;3Ci......	3	NE 5-10	1500 towering Cu all Quads.
	1800	88.5	80.0	----	----	0	4	4Cu;2Ci......	8	E 5-8	1800 towering Cu all Quads. Rain shwr NE in lagoon.
	2100	81.5	78.5	----	----	0.16	7	4Cu;4Ci......	9	E 5-10	1900 rain shwr began. 1910 stopped. 1920 rain shwr
8/31	0000	81.5	78.0	88.5	78.0	0.02	--	....	13	E 10-15	began. 1945 stopped. 2000 rain shwr began. 2010
	0300	82.5	77.5	----	----	0	--	....	12	E 10-15	stopped. 2100 towering Cu all Quads. Moonlight.
	0600	81.5	77.5	----	----	T	8	3Cu;3Ac;5Ci..	15	E 10-15	
	0900	84.5	79.0	----	----	0	7	3Cu;2Ac;5Ci..	13	E 10-12	1000-1100 calm wind.
	1200	90.0	82.0	90.0	81.5	0	8	2Cu;1Ac;5Ci..	11	E 5-8	1332-1338 light shwr.
	1500	88.0	80.0	----	----	T	7	5Cu;2Ac......	13	E 8	1517-1528 heavy shwr.
	1800	86.0	79.0	----	----	0.02	10	2Cu;8Ci,Cs...	12	E 5-8	1800 Cb in NW quadrant. 1850 heavy rain shwr E over
	2100	83.0	77.5	----	----	0	--	....	11	E 5-8	lagoon. 1905-1915 gusty winds at 15-20 kts. 2000
9/1	0000	79.0	76.5	91.0	79.0	0.35	--	....	11	E 3-5	halo around moon. 2325-0008 rain.
	0300	81.5	77.5	----	----	0.10	--	....	9	E 5	0420 rain started. 0545-0550 rain.
	0600	80.0	77.0	----	----	0.16	3	3Cu..........	9	SE 8-10	
	0900	83.0	78.5	83.0	78.0	T	10	4Cu;6Cs......	8	E 3-5	

PLACE: KEITH

HOURLY RELATIVE HUMIDITIES, AUGUST 18 - SEPTEMBER 1, 1957*

TABLE 9

HOUR:	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
DATE																								
8/18												67	66	65	64	64	63	62	65	71	72	74	75	78
8/19	78	78	76	74	75	83	83	79	73	68	66	65	63	65	61	65	71	74	75	75	76	77	78	80
8/20	80	80	80	78	79	74	76	71	68	66	63	59	59	59	60	61	64	66	67	73	76	76	76	78
8/21	80	82	93	83	85	83	79	79	77	78	79	80	79	76	73	74	76	76	80	81	82	83	81	84
8/22	82	82	84	86	87	81	81	81	79	74	78	80	70	66	63	67	72	78	77	77	76	81	85	86
8/23	86	84	86	86	86	87	88	84	86	85	82	74	76	73	70	76	80	84	83	82	82	80	80	80
8/24	86	86	82	84	84	85	85	81	80	80	84	82	68	67	69	67	74	72	76	80	80	80	78	80
8/25	80	81	82	79	76	76	77	76	74	72	70	76	68	66	58	59	60	60	66	72	80	84	85	85
8/26	82	83	78	74	78	82	82	80	74	80	74	70	70	72	67	62	67	70	75	82	83	84	82	82
8/27	--	--	78	--	--	86	--	--	84	--	--	77	--	--	69	--	--	66	--	--	82	--	--	84
8/28	--	--	82	--	--	80	--	--	75	--	--	72	--	--	67	--	--	77	--	--	86	--	--	82
8/29	--	--	82	--	--	83	--	--	77	--	--	71	--	--	68	--	--	81	--	--	80	--	--	82
8/30	--	--	82	--	--	80	--	--	72	--	--	75	--	--	72	--	--	69	--	--	86	--	--	86
8/31	--	--	80	--	--	83	--	--	79	--	--	71	--	--	71	--	--	73	--	--	78	--	--	89
9/1	--	--	83	--	--	87	--	--	82															

* Because of malfunctioning of the hygrothermograph only 3-hourly values are given 8/27 - 9/1.

DATE	TIME	TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	DDFF	SEA (Code)
8/18	1240	85.0	76.5	86.0	79.0	0.02	3	3Cu.........	S Light	---
8/19	1225	84.5	78.0	----	81.5	0	4	4Cu.........	E 6-8	---
8/20	1200	83.5	76.0	86.0	82.0	0	4	4Cu;Ci......	E 6-8	---
8/21	1200	82.5	77.5	85.0	77.5	0.11	8	2Cu;Ac;Ci...	SE 12-15	2
8/22	1200	83.0	75.5	84.0	79.0	0.13	9	2Cu;Ac;Ci...	NE 8-10	0
8/23	1200	83.0	78.5	85.0	80.5	0.21	8	2Sc;3Ac;7Ci.	NE 10-13	1
8/24	1200	81.5	76.0	85.0	77.0	0.27	7	4Cu;2Ac;6Ci.	E 6-8	0
8/25	1155	84.0	76.0	86.0	82.0	0	8	2Cu;4Ac;8Ci.	E 3-4	0
8/26	1200	85.0	78.5	88.0	78.0	0.09	7	4Cu;3Ac.....	SE 4	0
8/27	1200	84.0	78.0	85.0	78.5	0.24	6	5Cu;1Ac.....	SE 15	2
8/28	1130	85.0	79.0	84.0	82.0	0	10	3Cu;10As....	----	---
8/29	1200	85.5	79.0	85.0	81.5	0	4	4Cu.........	NE 10-12	1
8/30	1150	84.0	78.0	85.0	78.0	0.05	4	3Cu;2Ac;3Ci.	NE 3-4	0
8/31	1145	84.5	78.5	87.0	77.5	0.04	7	3Cu;3Ac;4Ci.	E 10-12	1

REMARKS AND TOWER READINGS

8/22 Towering Cu to S.

8/23 Cb to SW.

8/24 Light rain shwr. Several shwrs. in sight over lagoon and islets; heavy shwr. ½ mile N of MACK. TOWER: Platform #1 1220: TT-82.0; TT_w-77.0. Platform #2 1225: TT-81.0; TT_w-76.5. Platform #3 (on ladder at level of top) 1230: TT-81.0; TT_w-76.5.

8/25 Swelling cumulus on horizon along NE quadrant. TOWER: Platform #1 1207: TT-84.0; TT_w-76.0. Platform #2 1210: TT-83.0; TT_w-75.0. Platform #3 1215: TT-82.5; TT_w-75.5. Top 1213: TT-82.5; TT_w-75.5. (Platform #3 and Top are at same level; #3 was read on ladder at level of top; Top was read standing on top platform facing windward.)

8/26 Gentle swells, surface wind ripples. Heavy rain shwr. N of MACK; commenced 1230 and observed until after 1300. TOWER: Platform #1: TT-83.0; TT_w-78.0. Platform #2: TT-82.0; TT_w-77.0. Platform #3: TT-82.0; TT_w-77.0.

8/27 Moderate swells with white caps. Cloud conditions changed rapidly to following by 1230: N 10; 3Cu;7Ci. TOWER: Platform #1: TT-82.0; TT_w-78.0. Platform #2: TT-81.5; TT_w-77.5. Platform #3: TT-81.5; TT_w-76.5. At Shelter 1132: TT83.0; TT_w-77.5.

8/28 Hazy sun. TOWER: Platform #1 1115: TT-85.0; TT_w-78.0. Platform #2 1120: TT-84.0; TT_w-77.5. Platform #3 1125: TT-83.5; TT_w-77.0.

8/29 TOWER: Platform #1: TT-85.5; TT_w-79.0. Platform #2: TT-85.0; TT_w-79.0. Platform #3: (missing).

8/30 TOWER: Platform #1 1157: TT-83.0; TT_w-77.5. Platform #2 1200: TT-82.5; TT_w-77.5. Platform #3 1203: TT-82.2; TT_w-77.5. Top (Windward side) 1204: TT-82.0; TT_w-77.5.

8/31 Sea: code "1" plus. TOWER: Platform #1 1201: TT-84.0; TT_w-78.0. Platform #2 1203: TT-83.5; TT_w-78.0. Platform #3 1205: TT-84.0; TT_w-78.5. (poor exposure top shelter obstructing wind flow). Top (Windward side) 1208: TT-83.0; TT_w-79.0.

PLACE: MACK

BI-HOURLY TEMPERATURES AND RELATIVE HUMIDITIES, AUGUST 18 - 31, 1957

TABLE 11

HOUR:	0200		0400		0600		0800		1000		1200		1400		1600		1800		2000		2200		2400	
	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH
DATE																								
8/18													85	78	85	76	84	74	82	80	82	75	82	78
8/19	82	74	82	75	82	80	83	76	83	78	84	74	85	75	84	75	83	80	83	72	83	78	83	76
8/20	82	78	82	75	82	72	83	70	83	70	84	72	84	74	84	74	84	74	84	78	83	82	82	84
8/21	81	88	79	91	79	80	81	75	82	70	82	79	83	75	84	74	84	75	83	75	82	76	79	82
8/22	79	80	79	91	80	80	81	75	82	75	83	74	83	72	84	66	85	65	84	70	82	78	81	87
8/23	83	80	82	80	81	82	80	88	79	87	83	85	83	82	84	82	83	82	83	83	83	82	83	78
8/24	83	80	80	82	82	78	83	78	82	80	84	76	86	70	83	72	83	77	83	76	83	77	83	76
8/25	82	80	82	75	82	72	83	75	84	69	84	68	84	68	86	68	85	69	84	70	83	82	83	84
8/26	83	85	81	88	82	82	80	80	80	80	84	76	84	72	84	75	81	81	83	80	83	80	82	80
8/27	81	84	80	84	79	84	82	82	81	82	83	81	83	82	83	82	83	85	83	85	83	80	82	82
8/28	82	84	82	86	82	87	83	74	83	74	84	76	83	74	82	79	81	90	81	86	81	85	81	83
8/29	81	86	81	86	81	85	82	84	83	79	83	80	81	75	82	80	80*	82	80	82	81	83	80	86
8/30	80	85	80	85	80	80	81	82	81	85	83	74	82	76	82	80	81	86	80	87	77	89	80	90
8/31	80	86	80	82	80	80	81	82	81	87	84	78												

* 1900, 8/29, temperature 76°.

PLACE: ELMER   DAILY OBSERVATIONS, AUGUST 18 - SEPTEMBER 1, 1957   TABLE 12

DATE	TIME	TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	DDFF
8/18	0900	85.5	78.5	91.0	78.0	0	3	2Cu;1Ci.........	E 5-10
8/19	0915	85.5	79.0	93.0	84.0	0.02	2	2Cu............	E 5-10
8/20	0900	84.5	76.0	90.0	81.5	0	3	1Cu;2Ci.........	E 8-10
8/21	0900	83.0	77.0	89.0	76.5	0.52	10	3Cu;Ac;Cs.......	S 4-6
8/22	0900	81.5	77.5	88.0	80.0	0.14	10	9Cu,Sc;(Ac);(Ci)	N Very Lt.
8/23	0900	81.0	78.5	88.0	77.0	0.19	8	5Cu;3Ac;4Ci....	NE 8-10
8/24	0900	85.5	80.0	89.0	76.5	0.09	8	4Cu;2Ac;8Ci....	SE 4-6
8/25	0908	85.0	78.0	89.0	81.0	0	9	2Cu;1Ac;9Ci&Cs.	E 3-5
8/26	0900	82.0	78.5	90.0	82.0	0.18	9	6Cu;2Ac;2Ci....	Lt. Variable
8/27	0900	80.5	77.5	90.0	76.0	0.08	10	6Sc;4Cu.........	E 10-12
8/28	0850	85.0	77.5	88.5	80.0	T	10	2Cu;8Cs&Ci......	SE 2-4
8/29	0905	86.0	84.5	87.5	83.5	0.01	2	2Cu............	NE 0-5
8/30	0905	82.5	78.0	90.5	80.0	0.13	8	5Cu;2Ac;5Ci....	NE 3-6
8/31	0910	84.0	79.0	----	----	0.13	6	3Cu;4Ac;4Ci....	E 8-10
9/1	1015	84.0	81.0	88.0	77.5	0.20	8	3Cu;4Ac;7Ci....	E 6-8

REMARKS

8/22	0900	Rain.
8/23	0900	Shwrs. to the north.
8/24	0900	Shwrs. in sight. Swelling cumulus over the lagoon to the NW.
8/25	0908	Swelling cumulus far distant to the NE.
8/26	0900	Towering cumulus in all quadrants. Shwr. from 0852 to 0905.
8/27	0900	Shwr. from 0904 to 0912.
8/30	0905	Shwrs. in sight in all quadrants.
9/1	1015	Towering cumulus in the north quadrant.

PLACE: ELMER

BI-HOURLY TEMPERATURES AUGUST 20 - SEPTEMBER 1, 1957

TABLE 13

HOUR:	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	2400
DATE												
8/20					84	87	88	88	86	82	82	80
8/21	78*	77	78	79	82	85	86	86	85	81	80	80
8/22	79	77	79	81	78	80	86	84	82	82	81	78
8/23	80	78	79	80	80**	84	87	85	83	81	81	82
8/24	81	81	81	81	86	87	87***	86	85	82	82	81
8/25	81	81	80	82	87	88	89	89	86	84	81	81
8/26	78	79	80	82	80	84	87	88	84	81	81	81
8/27	78	79****	80	81	81	84	86	86	83	81	80	80
8/28	80	80	79	81	85	84	84	83	80	80	79	79
8/29	79	80	80	81	85	88*****	88	87	79	80	81	81
8/30	80	80	80	82	78	85	86	86	85	80	80	80
8/31	80	80	80	81	83	84	85	86	85	82	81	77
9/1	79	79	79	80	83	86						

* Just before 0300, 8/21, temperature drops to 76°.
** 0900, 8/23, temperature 81°.
*** 1300, 8/24, temperature 88°.
**** 0500, 8/27, temperature 77°.
***** 1300, 8/29, temperature 89°.

PLACE: JANET

TABLE 14

DAILY RAINFALL, AUGUST 19 - 31, 1957

DATE	TIME	RR	REMARKS
8/19	0915	0.50	Total since 0915, 8/17/57.
8/20	0915	0	
8/21	0915	0.22	
8/22	0915	0.13	
8/23	0915	0.10	
8/24	0945	0.19	
8/25	----	*	
8/26	0945	0.11	
8/27	0945	0.81	
8/28	0915	0	
8/29	0915	0	
8/30	0915	0.15	
8/31	0915	0.01	

* Amount included in total for next day.

DATE	ZONE	TIME	TT_s	TIME	TT	TT_w	REMARKS
8/18		1128					Departed ELMER.
	1	1132	84.0*	1137	87.0	78.5	300 yards off ELMER.
	2	1150	84.5*	1155	88.0	79.5	Off buoy.
	3	1210	84.5*	1215	88.0	79.0	
	4	1230	85.0*	1233	87.0	79.0	
	5	1243	84.5*				100 feet off MACK.
		1247					Arrived MACK.
		1410					Departed MACK.
	5	1415	85.5*	1420	84.0	78.0	100 feet west of MACK.
	4	1435	84.5*	1442	83.5	78.0	
	2	1455	84.5*	1502	83.0	77.5	
	1	1525	84.0*				300 yards off ELMER.
		1530					Arrived ELMER.
8/19		1057					Departed ELMER.
	1	1101	84.0*	1105	84.0	79.0	300 yards off ELMER.
	2	1121	84.0*	1125	83.5	78.5	Off buoy.
	3	1141	84.5*	1145	83.5	79.0	
	4	1201	84.5*	1205	83.5	78.5	
	5	1218	84.5*				150 feet off MACK.
		1222					Arrived MACK.
		1300					Departed MACK.
	5	1303	84.5*	1308	85.5	78.5	45 feet west of MACK.
	4	1325	84.5*	1328	84.5	79.0	
	3	1345	84.5*	1350	84.5	78.5	
	2	1405	84.0*	1410	84.5	78.5	
	1	1432	84.0*				300 yards off ELMER.
		1440					Arrived ELMER.
8/20		1016					Departed ELMER.
	1	1019	83.5*	1024	83.5	77.5	300 yards off ELMER.
	2	1039	83.5*	1044	83.5	77.0	Buoy to starboard.
	3	1059	84.0*	1104	85.0	77.0	
	4	1119	84.0*	1123	84.5	77.5	
	5	1135	84.0*				300 feet off MACK.
		1142					Arrived MACK.
		1220					Departed MACK
	5	1225	84.5*				50 feet west of MACK.
	4	1245	84.0*	1250	84.5	78.0	
	3	1305	84.0*	1310	84.5	78.0	
	2	1325	84.0*	1330	84.5	77.5	Off buoy.
	1	1347	83.5*				300 yards off ELMER.
		1350					Arrived ELMER.
8/21		1019					Departed ELMER.
	1	1021	83.5*	1025	84.5	79.0	At green water.
	2	1041	83.5*	1043	83.5	78.0	Obstruction buoy "A" to port.
	3	1059	84.0*	1102	83.5	78.5	Black buoy "11" nearby.
	4	1117	84.0*	1118	83.5	78.5	OSCAR off starboard bow.
	5	1133	84.0*	1134	83.0	78.5	300 yards off MACK.
	5	1136	84.0*				200 feet off MACK.
		1148					Arrived MACK. M-boat had to lay off tower because of sea condition.
		1220					Departed MACK.
	5	1225	84.0*	1226	83.5	78.5	200 feet off MACK.
	4	1241	84.0*	1244	83.5	77.5	OSCAR off port bow.
	3	1305	84.0*	1306	82.5	77.5	Black buoy to starboard.
	2	1337	84.0*	1338	82.0	77.0	
	2	1350	84.0*	1352	82.5	78.0	Red lighted buoy to starboard.

DATE	ZONE	TIME	TT_s	TIME	TT	TT_w	REMARKS
8/21	1	1406	83.5*				At green water.
		1410					Arrived ELMER.
8/22		1005					Departed ELMER.
	1	1007	83.5	1009	81.5	78.0	Rain shwrs between 1015 and 1100.
	2	1025	83.7	1027	80.5	78.0	"A" buoy to port.
	3	1043	83.7	1046	80.0	77.5	Buoy to port.
	4	1100	83.8	1102	80.5	77.5	
	4	1118	84.0	1121	81.0	77.5	1,500 yards off MACK.
	5	1123	84.0				150 feet off MACK.
		1125					Arrived MACK.
		1245					Departed MACK.
	5	1246	84.5	1248	83.0	77.5	50 feet off MACK.
	4	1304	84.3	1307	84.0	78.5	
	3	1323	84.2	1325	84.0	78.5	Black buoy to port.
	2	1342	84.3	1344	84.0	78.5	
	2	1356	84.0	1359	83.5	77.5	
	1	1404	84.0				At green water.
		1406					Arrived ELMER.
8/23		1020					Departed ELMER.
	1	1023	83.5	1025	82.0	78.5	At green water.
	2	1040	83.8	1044	82.0	78.5	Buoy "A" to port.
	3	1058	83.7	1101	82.5	79.0	Black buoy "11" to port.
	4	1116	84.0	1119	83.0	78.5	OSCAR off the starboard bow.
	4	1131	84.0	1134	83.0	79.5	OSCAR off the starboard quarter.
	5	1138	84.0				150 feet off MACK.
		1140					Arrived MACK.
		1240					Departed MACK.
	5	1240	84.3	1242	83.5	78.5	50 feet off MACK.
	4	1258	84.0	1300	83.5	78.5	OSCAR off the port quarter.
	3	1317	84.0	1319	83.5	78.5	Between a black and a red buoy.
	2	1335	84.0	1338	83.0	79.0	Buoy "A" to port.
	2	1350	83.5	1353	84.5	79.0	Buoy "8" to starboard.
	1	1400	83.8				At green water
		1405					Arrived ELMER.
8/24		1020					Departed ELMER.
	1	1025	84.0	1030	84.5	78.5	500 yards off ELMER.
	2	1043	84.0	1050	86.5	78.5	Black buoy on starboard beam.
	3	1104	84.0	1109	83.0	78.5	Red lighted buoy on starboard quarter.
	4	1125	84.0	1130	83.0	78.5	OSCAR on starboard beam.
	5	1136	84.0				300 feet off MACK.
		1138					Arrived MACK.
		1235					Departed MACK.
	5	1236	84.8	1045	83.5	77.5	150 feet off MACK.
	4	1256	85.2	1303	83.0	78.0	OSCAR on the port quarter.
	3	1316	84.8	1320	84.0	78.5	Black buoy "11" off starboard beam.
	2	1338	84.7	1342	84.5	77.5	BRUCE on port beam.
	2	1348	83.9	1354	84.5	78.0	Black channel (inside) buoy on port beam.
	1	1355	84.0				Inside green water.
		1356					Arrived ELMER.
8/25		1020					Departed ELMER.
	1	1022	84.0	1025	83.5	76.5	At edge of green water.
	2	1040	84.0	1045	83.0	76.8	Obstruction buoy "A" off starboard bow.
	3	1100	84.5	1103	83.5	77.0	Black buoy "11" off starboard beam.
	4	1121	84.5	1125	83.0	76.5	OSCAR on starboard bow.
	5	1140	84.5				
		1142					Arrived MACK.

DATE	ZONE	TIME	TT_s	TIME	TT	TT_w	REMARKS
8/25		1220					Departed MACK.
	5	1222	84.8	1228	85.5	76.5	150 feet off MACK.
	4	1242	84.8	1248	85.5	77.0	OSCAR on port quarter.
	3	1301	85.0	1305	84.5	76.5	Black buoy "11" off port beam.
	2	1321	85.0	1325	85.2	75.6	Obstruction buoy "A" off port beam.
	2	1335	83.9	1340	84.5	77.0	At red buoy "6". Current (about 6 knots) running into lagoon at red buoy "6".
	1	1342	84.4				At edge of the green water.
		1344					Arrived ELMER.
8/26		0945					Boat departed BRUCE rather than ELMER.
	2	0950	83.5	1000	84.0	79.5	100 yards from shore.
	3	1010	83.8	1020	84.0	79.0	Intermittent shwrs. 1015-1100.
	4	1030	83.5	1035	84.0	79.5	Buoy 400 yards to port.
	5	1050	83.2	1055	82.5	78.5	300 yards off MACK. All readings taken by holding bulb-end into wind.
		1100					Arrived MACK.
		1230					Departed MACK.
	5	1235	84.2	1240	83.5	78.5	200 yards off MACK.
	4	1255	84.7	1300	84.5	78.0	
	3	1315	85.0	1320	84.0	78.0	Heavy rain shwr. N of MACK still visible at 1330.
	2	1335	84.0	1340	84.0	78.0	300 yards south of red buoy "A".
	1	1353	84.0	1357	85.0	78.5	300 yards off ELMER. All readings taken by holding bulb-end into wind.
		1400					Arrived ELMER.
8/27		1007					Departed ELMER.
	1	1010	83.7	1013	83.5	79.0	300 yards off shore.
	2	1030	83.7	1032	84.5	79.0	Red buoy 400 yards to starboard.
	3	1050	84.1	1052	84.5	79.5	
	4	1110	84.4	1113	85.0	79.5	
		1120					Arrived MACK.
		1255					Departed MACK.
	5	1300	84.5	1302	83.5	79.0	300 yards off MACK.
	4	1320	84.3	1323	84.0	79.0	
	3	1340	84.3	1342	85.0	79.0	Black buoy 300 yards to port.
	2	1400	84.3	1402	85.0	79.0	Obstruction buoy 200 yards to port.
	1	1418	84.0	1420	86.0	79.0	300 yards off ELMER.
		1423					Arrived ELMER.
8/28		0950					Boat departed BRUCE rather than ELMER.
	2	0955	83.9	0957	84.5	78.0	At blue water-heading 300°.
	3	1015	84.0	1016	84.0	78.5	Heading 300°.
	4	1036	84.1	1035	84.5	78.0	Heading 300°.
	5	1051	84.1	1050	85.0	78.5	Off MACK.
		1053					Arrived MACK.
		1220					Departed MACK.
	5	1220	84.4	1225	86.0	79.0	Few yards off MACK.
	4	1240	84.0	1242	85.0	79.0	
	3	1300	84.2	1303	85.0	78.0	Buoy "11".
	2	1320	83.9	1324	84.0	78.5	
	1	1335	83.5	1334	84.5	78.0	At edge of blue water.
		1339					Arrived ELMER.
8/29		1010					Departed ELMER.
	1	1018	83.5*	1020	84.5	78.5	Buoy and REX in line.
	2	1035	84.0*	1038	84.5	78.5	
	3	1055	85.0*	1057	84.5	79.0	
	4	1115	84.5*	1118	84.0	79.0	

DATE	ZONE	TIME	TT_s	TIME	TT	TT_w	REMARKS
8/29	5	1130	84.5*	1128	85.5	80.0	
		1130					Arrived MACK.
		1222					Departed MACK.
	5	1222	85.0	1224	87.5	80.0	Few yards off MACK.
	4	1240	84.5	1243	87.0	80.5	
	3	1300	84.5	1302	86.0	80.0	
	2	1320	84.0	1322	85.5	79.0	
	1	1335	84.5	1338	86.0	79.5	
		1340					Arrived ELMER.
8/30		1013					Departed ELMER.
	1	1015	83.3	1020	80.5	77.0	150 yards off ELMER. Rain shwr. 300 yards ahead.
	2	1033	83.3	1037	80.5	77.0	Obstruction buoy "A" on starboard beam. Rain shwr. 1000 yards off port bow.
	3	1055	83.8	1100	81.0	76.5	OSCAR on starboard bow.
	4	1115	84.4	1119	83.0	79.0	OSCAR on starboard beam.
	5	1133	84.4				200 feet off MACK. Many shwrs. over lagoon at start of traverse; all dissipated by noon.
		1135					Arrived MACK.
		1211					Departed MACK.
	5	1213	85.4				150 feet off MACK.
	4	1225	85.2	1229	83.5	77.0	OSCAR on port beam.
	3	1245	85.2	1248	83.5	78.5	Black buoy "11" 500 yards ahead.
	2	1306	84.8	1310	83.0	79.0	Obstruction buoy "A" off port beam.
	2	1320	84.5	1323	83.5	79.0	Cement barge off port beam.
	1	1325	84.5				At blue water's edge.
		1327					Arrived ELMER.
8/31		1023					Departed ELMER.
	1	1025	83.9	1027	84.0	79.0	At edge of blue water.
	2	1045	83.8	1048	84.0	78.5	Obstruction buoy "A" on port quarter.
	3	1105	84.2	1108	84.0	79.0	Black buoy "11" astern 1000 yards.
	4	1125	84.4	1127	84.5	79.0	OSCAR off starboard beam.
	5	1135	84.5				300 feet off MACK.
		1138					Arrived MACK.
		1245					Departed MACK.
	5	1250	84.5	1252	86.0	79.0	1000 yards off MACK.
	4	1315	84.5	1317	85.5	78.0	OSCAR on port quarter.
	3	1338	84.4	1340	85.0	80.0	Black buoy "11" on port quarter.
	2	1401	83.9	1408	85.5	79.5	Red lighted buoy "12" off port beam.
	1	1420	83.8				At edge of blue water.
		1422					Arrived ELMER.

* **Temperatures read to nearest 0.5° F. only.**

PLACE: BETWEEN BRUCE, KEITH, ELMER

TABLE 16

LAGOON TRAVERSES, AUGUST, 1957

Traverse No. 1, BRUCE-KEITH

DATE	TIME	TT_s	TIME	TT	REMARKS
20th	0945	83.7	0945	88.0	In shallow water by BRUCE departing for KEITH.
	0950	83.8	0950	86.0	
			0955	85.0	
	1000	84.2	1000	85.0	
			1005	85.0	
	1010	84.2	1010	86.0	Near obstruction buoy "A".
			1015	85.0	
	1020	84.0	1020	85.0	
			1025	85.0	
	1030	84.2	1030	84.5	
	1040	84.2	1040	84.5	
			1045	85.0	
	1050	84.0	1050	84.5	
			1055	85.0	
	1100	84.0	1100	85.0	
			1105	85.0	
	1110	84.2	1110	85.5	
	1115	84.4	1115	85.0	
	1120	84.6	1120	87.0	Water shoaling.
	1125	84.6	1125	86.0	100 yards from shore.
	1128	84.2	1128	89.0	At shore - KEITH.
	1203	83.8	1203	87.0	About 50 yards from shore.
	1205	84.6	1205	86.0	50 yards to blue water. Course 110°.
	1210	84.6	1210	85.5	Deep water. Course 115°.
	1220				Thermometer broke, observations discontinued.

Traverse No. 2, ELMER-KEITH-BRUCE

DATE	TIME	TT_s	TIME	TT	REMARKS
23rd	1030				Departed ELMER.
	1025	84.0	1025	84.0	ELMER landing.
	1030	83.8	1030	87.0	Heading 245-250°. Hazy sun.
			1035	84.0	
	1040	84.0	1040	84.0	Heading 245°.
			1045	84.5	
	1050	84.0	1050	84.5	Heading 250°.
			1055	84.5	Passing buoy.
	1100	84.2	1100	85.0	Heading 250°. 1104 passing buoy.
			1105	85.0	
	1110	84.2	1110	85.0	Heading 250°.
			1115	85.0	
	1120	84.2	1120	85.0	Heading 250°.
			1125	85.0	
	1130	84.6	1130	85.0	
			1135	85.0	
	1140	84.4	1140	85.5	
			1145	85.0	
	1150	84.4	1150	85.0	
	1155	84.4			At edge of blue water.
	1200	83.3			At buoy.
	1205	84.0			Halfway from buoy to shore on KEITH.
	1210	85.1			At KEITH, but still in water (at edge of shore).
	1220	84.0			Halfway from shore to buoy (starting now for BRUCE).
	1225	83.8			At buoy.
	1320				Departed KEITH.
	1325	84.4	1325	86.0	At edge of blue water.

PLACE: BETWEEN BRUCE, KEITH, ELMER

TABLE 16
(Continued)

LAGOON TRAVERSES, AUGUST, 1957

Traverse No. 2, ELMER-KEITH-BRUCE

DATE	TIME	TT_s	TIME	TT	REMARKS
23rd	1330	84.4	1330	84.0	Heading 70° true.
			1335	84.0	
	1340	84.2	1340	84.0	Heading 70° true.
			1345	84.5	
	1350	84.4	1350	84.5	Heading 75° true.
			1355	84.5	
	1400	84.4	1400	84.0	Heading 75° true.
			1405	84.5	
	1410	84.4	1410	84.0	
			1415	84.5	
	1420	84.4	1420	84.5	
			1425	84.5	
	1430	84.3	1430	84.0	
			1435	83.0	
	1440	84.1	1440	84.0	Cloudy with light shwrs.
			1445	83.0	
	1450	84.2	1450	84.0	100 yards S of buoy "A".
			1455	83.0	
	1500	84.2	1500	83.0	
			1505	82.0	Heavy rain on BRUCE.
	1510	84.1	1510	83.0	
	1515	84.1	1515	82.0	At edge of blue water.
	1518	84.8	1518	86.0	200 yards off shore.
	1521	84.9	1521	85.0	100 yards off shore.
	1525	85.3	1525	85.5	Along shoreline at BRUCE.
			1527	84.8	Inshore.

Traverse No. 3, KEITH-BRUCE

DATE	TIME	TT_s	TIME	TT	TT_w	REMARKS
28th	1045					Departed KEITH.
			1043	88.0	81.0	Edge of vegetation on shore at KEITH.
	1045	85.0*	1045	86.5	79.0	Edge of water.
	1050	84.0*	1052	85.0	79.0	5 yards from KEITH.
	1055	84.0*	1057	84.5	80.0	100 yards from buoys at KEITH.
	1100	84.0*	1102	84.0	80.0	
	1110	84.5*				
	1120	84.5*	1122	85.5	79.5	
	1130	84.5*	1132	85.0	79.0	
	1140	84.5*	1142	85.0	79.0	
	1150	84.5*	1152	84.5	78.5	
	1200	84.0*	1202	85.0	79.0	
	1210	84.0*	1212	85.0	78.5	
	1215					Buoy "A".
	1220	84.0*	1222	85.0	79.0	
	1230	84.0*	1232	84.5	78.0	
	1235	84.0*	1237	85.0	78.0	
	1240	84.0*	1241	85.0	78.0	
	1242	84.5*	1242	85.0	78.0	100 yards from BRUCE.
	1244	84.5*	1244	85.0	77.5	25 yards from BRUCE.
	1245	85.0*	1245	85.0	78.5	Edge of water.
			1247	85.5	78.5	Edge of vegetation on BRUCE.

PLACE: BETWEEN BRUCE, KEITH, ELMER

TABLE 16
(Concluded)

LAGOON TRAVERSES, AUGUST, 1957

Traverse No. 4. BRUCE-KEITH-ELMER

DATE	TIME	TT_s	TIME	TT	TT_w	REMARKS
31st	0930					Departed BRUCE.
			0927	86.0	79.5	Edge of vegetation on BRUCE.
	0929	84.2	0929	85.0	79.0	Edge of water.
	0951	84.2	0951	86.5	80.0	50 yards from water's edge.
	0954	84.0	0954	86.0	79.5	Edge of blue water.
	1000	84.0	1000	86.5	80.0	Course 250°.
	1015	84.2	1015	86.5	79.0	Course 250°.
	1030	84.2	1030	86.0	79.5	Course 250°.
	1045	84.6	1045	86.0	79.5	Course 240°.
	1100	84.6	1100	87.0	80.5	Course 240°. 1103 passed red buoy (50 gallon drum on coral head.
	1115	84.7	1115	87.0	80.0	Course 240°.
	1125	84.7	1125	87.0	80.0	Course 240°.
	1130	84.7	1130	86.5	80.0	
	1132	84.6	1132	86.5	80.5	Between KEITH buoys.
	1134	85.3	1134	86.5	80.5	10 yards from water's edge.
	1136	86.4	1136	85.5	80.0	Edge of water.
			1138	86.0	79.5	Edge of vegetation on KEITH.
	1200					Departed KEITH.
			1155	88.0	80.5	Edge of vegetation.
	1157	86.9	1157	86.5	80.0	Edge of water.
	1158	85.6	1158	87.0	81.0	15 yards from water's edge.
	1203	84.7	1203	85.0	79.5	Passed buoy.
	1208	84.7	1208	87.0	80.5	Course 080°.
	1225	85.1	1225	86.0	79.5	Course changed to 070°.
	1240	84.9	1240	86.0	80.0	Course from 070 to 065°.
	1255	84.7	1255	85.5	79.5	Course 060°.
	1310	84.6	1310	86.0	80.0	Passed obstruction buoy; Course 060°. 1318 - 1321 rain shwr.
	1325	84.6	1325	85.5	79.5	Passed lighted buoy; Course 065°.
	1340	84.4	1340	85.5	79.5	Course 065°.
	1350	84.2	1350	86.0	79.0	Passed buoy "B-1".
	1356					Arrived ELMER.

LAGOON-OCEAN TRAVERSES, AUGUST, 1957

DATE	TIME	TT_s	REMARKS
18th	1025	83.5	From helicopter. About 500 yards off ELMER reef, in ocean.
	1042	83.7	From helicopter. About 500 yards off KEITH reef, in ocean.

DATE	TIME	TT_s	TIME	TT	TT_w	REMARKS
23rd	1150					Departed ELMER
	1156	83.0*	1158	85.0	80.0	In deep channel entrance.
	1203	83.0*	1206	84.5	79.5	Off entrance buoy "2".
	1217	83.0*	1219	85.0	80.0	Outside E of BRUCE.
	1232	83.0*	1235	86.0	80.0	Outside NE of SAM.
	1248	83.0*	1250	85.0	80.0	Outside E of BRUCE.
	1304	83.5*	1306	85.5	80.0	Outside E of ELMER.
	1320	83.5*	1322	85.0	79.5	Outside E of FRED.
	1333	83.0*	1335	84.5	79.0	Off black "1" buoy, SW of FRED.
	1342	84.0*	1350	85.0	79.5	In lagoon W of Sand Island.
	1400					Arrived ELMER.

PLACE: ENIWETOK-BIKINI

BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 18

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/18	0200	Bikini	2	Lt.Airs	03	72	82	78		2	2	20					
	0400	Bikini	2	Lt.Airs	02	70	81	78		2	2	20					
	0600	Bikini	2	Lt.Airs	02	72	80	78		2	2	20					
	0800	Bikini	2	Lt.Airs	02	72	83	78		2	2	20					
	1000	Bikini	2	09-05	02	86	87	80		2	2	20					
	1200	Bikini						N O	R E P O R T S								
	1400	Bikini						N O	R E P O R T S								
	1600	Bikini						N O	R E P O R T S								
	1800	Bikini	4	11-08	03	76	86	80		3	2	20	--	1			
	2000	Bikini	6	11-05	02	92	82	78		6	2	20	--	--			
	2200	Bikini	2	11-05	01	90	82	78		2	2	20	--	--			
	2400	Bikini	0	11-05	02	90	82	78		-	-	--	--	--			

LOG ENTRIES:

0000-0200 LST Cargo Pier, Enyu Is., Bikini Atoll: Lat 11°30.7'N-Long 165°33.5'E. Light airs, sky mostly clear with scattered cumulus clouds, visibility unlimited. Barometer steady. Bright moonlight.
0200-0400 Position as before. No change in weather.
0400-0600 Position as before. No change in weather.
0600-0800 Position as before. No change in weather in past 8 hours. Barometer steady. Light variable airs.
0800-1000 Position as before. Visibility unlimited. Slight easterly breeze. Low SW swell.
1000-1200 Position as before. Visibility unlimited. Low SW swell.
1200-1400 Position as before. Cloud cover increasing. Shower in sight to NW. East to south breeze strengthening.
1400-1600 Position as before. Clear overhead. Banks of cumulus cloud all around horizon, heaviest to eastward.
1600-1800 Position as before. Cumulus clouds all around horizon. Filaments or strands of cirrus clouds overhead. Visibility unlimited. Barometer rising.
1800-2000 Position as before. Barometer came up .16 in past 2 hours. Clouds becoming more developed. No change in wind.
2000-2200 Position as before. Clouds dissolving. Visibility unlimited.
2200-2400 Position as before. No clouds. Barometer steady. Visibility unlimited.

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/19	0200	Bikini	6	10-05	18	85	81	78		5	2	20	--	1			
	0400	Bikini	6	11-05	18	87	81	78		5	2	20		1			
	0600	Bikini	3	08-10	01	86	82	77		3	2	20	--	1			
	0800	Bikini						N O	R E P O R T S								
	1000	Bikini	3	08-10	01	80	87	80		3	2	20	--	--			
	1200	Bikini	3	08-10	02	80	86	79		3	2	20	--	--			
	1400	Bikini	3	09-10	02	74	87	79		3	2	20					
	1600	Bikini	2	07-08	01	72	86	79		2	2	20					
	1800	Bikini	2	06-10	02	77	84	78		2	2	20	0	1			
	2000	Bikini	2	08-10	02	80	83	77		2	2	20	0	1			
	2200	Bikini	0	05-10	02	80	82	76		-	-	--	--	--			
	2400	Bikini	0	05-10	02	80	82	77		-	-	--	--	--			

PLACE: ENIWETOK-BIKINI

BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 18 (Continued)

8/19

LOG ENTRIES:

0000-0200 LST Cargo Pier, Enyu Is., Bikini Atoll: Lat 11°30.7'N-Long 165°35.5'E. Rain squalls to northeasterly around horizon. Light southeasterly breeze. Barometer dropping slowly. Low southwesterly swells. Excellent visibility except toward rain squalls. Sky mostly cloudy.
0200-0400 Position as before. Occasional light rain squalls. Barometer rising slowly. Slight east-southeasterly breeze. Excellent visibility except in rain squalls.
0400-0600 Position as before. Visibility excellent. Sky clearing. Low swell from southwest.
0600-0800 Position as before. Visibility excellent. Low southwest swell.
0800-1000 Position as before. Cumulus clouds all around horizon. Clear overhead. Barometer dropped .80 in past 2 hours. Visibility unlimited.
1000-1200 Position as before. No change in weather conditions.
1200-1400 Position as before. Towering cumulus clouds around horizon. Clear overhead. Barometer dropping slowly. Variable light wind from east to east-northeasterly. Unlimited visibility.
1400-1600 Position as before. No change in weather.
1600-1800 Position as before. Visibility excellent.
1800-2000 Position as before. Visibility excellent. Low confused swell.
2000-2200 Position as before. No clouds. Barometer steady. Visibility unlimited.
2200-2400 Position as before. No change in weather. Barometer steady. Visibility unlimited.

DATE	TIME	POSITION	COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/20	0200	Bikini		2	05-10	03	78	82	77	--	2	2	20					
	0400	Bikini		2	05-10	02	76	82	78	--	2	2	20					
	0600	Bikini		2	10-03	02	76	82	77		2	2	20					
	0800	Bikini		2	08-05	02	79	83	77		2	2	20					
	1000	Bikini		3	08-08	02	93	86	79		2	2	20	--	1			
	1200	11°27.5'N 165°25'E	253	3	08-05	02	91	88	80		2	2	20	--	1	08	4	2
	1400	11°26'N 165°05'E	269	2	08-10	01	86	88	79	86	T	2	20	--	1	08	4	2
	1600	11°26'N 164°46'E	269	2	08-08	02	82	88	79	86	1	2	20	--	1	08	4	2
	1800	11°27'N 164°26'E	265	2	04-08	02	82	88	79		2	2	20	0	9	04	-	1
	2000	11°27'N 164°07'E	265	2	05-08	02	82	84	78		2	2	20	0	9	04	-	1
	2200	11°25'N 163°50.0'E	265	5	08-05	03	92	84	78		5	2	20	--	--	08	5	2
	2400	11°24.0'N 163°32'E	270	2	08-05	16	92	83	78		2	2	20	--	--	08	5	2

LOG ENTRIES:

0000-0200 LST Cargo Pier, Enyu Is., Bikini Atoll: Lat 11°30.7'N-Long 165°35.5'E. Sky mostly clear with scattered cumulus clouds around horizon. Light northeasterly breeze. Bright moonlight with unlimited visibility. Barometer steady.

PLACE: ENIWETOK-BIKINI — BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957 — TABLE 18 (Continued)

DATE	TIME	POSITION/COURSE		N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/20																		

LOG ENTRIES:

0200-0400 Position as before. No change in weather for past 4 hours. Barometer dropping slowly.
0400-0600 Position as before. Visibility excellent. Low SW swell.
0600-0800 Position as before. Visibility excellent. Low SW swell.
0800-1000 Position as before. Cumulus clouds all around horizon. Strands of cirrus overhead. Barometer rising. Visibility unlimited.
1000-1200 En route Bikini to Parry Is*: Lat 11°27.5'N-Long 165°25'E. No change in weather. Visibility unlimited.
1200-1400 (1400 Position: 11°26'N-Long 165°05'E) Sky mostly clear with towering cumulus clouds around horizon. Thin strands of cirrus overhead. Bright sunshine. Visibility unlimited. Light northeasterly breeze and sea. Barometer dropping slightly in past 2 hours.
1400-1600 (1600 Position: 11°26'N-Long 164°46'E) No change in weather for past 4 hours.
1600-1800 (1800 Position: 11°27'N-Long 164°26'E) Visibility excellent. Low short easterly swell. Long low NW swell.
1800-2000 (2000 Position: 11°27'N-Long 164°07'E) Visibility excellent. Low short easterly swell. Long low NW swell.
2000-2200 (2200 Position: 11°25'N-Long 163°50.0'E) Clouds forming. Barometer jumped .10 in past 2 hours. Visibility unlimited. 2210: rain squalls on radar scope ⊘315°T 24.0 mi. off port bow. 2253: lightning observed in NE.
2200-2400 (2400 Position: 11°24.0'N-Long 163°32'E) Rain squalls on radar scope. Visibility unlimited. Lightning north and northeast. Barometer steady.

DATE	TIME	POSITION/COURSE		N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT.	C_L TYPE	C_L HT.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT.
8/21	0200	11°25'N 163°17'E	270	4	18-12	18	88	81	78	85	4	2	20			18	3	2
	0400	11°25'N 162°59'E	265	8	19-10	18	86	80	77	85	7	2	20	--	1	18	3	2
	0600	11°26'N 162°43'E	258	4	21-05	80	84	82	78		4	2	20			21	-	1
	0800	11°25'N 162°25'E	VAR	7	21-05	03	86	83	78		7	7	20			21	-	1
	1000	Eniwetok		6	17-08	01	86	83	77		5	7	20	--	1	17	-	1
	1200	Eniwetok		5	18-10	01	80	83	77		4	7	20	--	1	18	-	1
	1400	Eniwetok		5	19-12	16	76	84	78		4	7	20	--	1	19	-	1
	1600	Eniwetok							NO REPORTS									
	1800	Eniwetok							NO REPORTS									
	2000	Eniwetok							NO REPORTS									
	2200	Eniwetok		1	19-08	01	82	83	78		1	2	20	--	--	19	-	1
	2400	Eniwetok							NO REPORTS									

LOG ENTRIES:

0000-0200 En route Bikini to Parry Is.*: (0200 Position: Lat 11°25'N-Long 163°17'E). 0020: wind shifted from ESE to south. Moderate southerly wind 10 to 12 knots. Numerous small rain squalls noted on radar. Flashes of lightning observed to NW. Unlimited visibility. Barometer dropped .04 in past 2 hours. Light southerly sea and low southeasterly swell.
0200-0400 (0400 Position: Lat 11°25'N-Long 162°59'E) Numerous light rain squalls. Good visibility except in squalls. Lightning observed to westerly. Sky mostly overcast. Light southwesterly wind and sea.
0400-0600 (0600 Position: Lat 11°26'N-Long 162°43'E) Visibility unlimited. Low NE swell. Sighted loom of Eniwetok aero-beacon light 25 miles.

*Parry is the native name for Elmer Islet, Eniwetok.

PLACE: ENIWETOK-BIKINI   BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957   TABLE 18 (Continued)

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/21																	

LOG ENTRIES:

0600-0800 (0800 Position: Lat 11°25'N-Long 162°25'E) Visibility excellent. 0615: ship commenced to roll heavily, moderate average southerly swell.
0800-1000 (1000 Position: Anchored off Parry (Elmer) Is. - Anchorage "Cl") Moderate southeasterly wind. Sky mostly overcast. Visibility 12-15 miles. Rain squalls around horizon. Barometer steady. Light southerly sea inside Eniwetok lagoon.
1000-1200 Anchored as before. Weather as before except sky clearing slightly. Barometer dropped .06 during past 2 hours.
1200-1400 Position as before. Visibility unlimited. Barometer falling. Southerly winds.
1400-1600 Position as before. Moderate southerly winds. Excellent visibility.
1600-1800 Position as before. Visibility unlimited. Low short SW swell.
1800-2000 Position as before. Visibility excellent. Low SW swell.
2000-2200 Position as before. No change in wind or weather conditions. Visibility unlimited.
2200-2400 Position as before. Southerly breeze. Visibility excellent. Barometer rising.

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/22	0200	Eniwetok	7	18-05	18	82	83	78		7	7	20			19	--	1
	0400	Eniwetok	7	09-05	18	80	83	78		7	7	20			18	--	1
	0600	Eniwetok	8	24-08	18	79	83	78		8	7	20			20	--	1
	0800	Eniwetok	7	24-05	01	80	83	78		7	7	20			--	--	-
	1000	Eniwetok	8	04-10	81	86	81	79		8	7	20	--	--	--	--	-
	1200	Eniwetok	6	05-08	81	90	82	79		8	7	20	--	--	--	--	-
	1400	Eniwetok	6	05-08	01	84	86	80		3	2	20	5	1	--	--	-
	1600	Eniwetok	7	05-08	03	82	84	78		7	7	20	--	--	--	--	-
	1800	Eniwetok	7	05-08	02	80	82	78		7	7	20					
	2000	Eniwetok	6	05-10	02	82	81	78		6	7	20					
	2200	Eniwetok	6	07-15	15	86	83	78		6	2	20	--	--	--	--	-
	2400	Eniwetok	6	08-15	15	86	82	78		6	2	20	--	--			

LOG ENTRIES:

0000-0200 Anchored off Parry (Elmer) Is. in Anchorage "Cl". Light southerly wind. Moderate southerly swell with slight southerly sea. Excellent visibility with rain squalls to south. Barometer steady.
0200-0400 Position as before. Light rain squalls. Long, low, choppy southerly swell. Light southerly sea. 0340: wind suddenly shifted to easterly. Rain squalls moving from easterly direction.
0400-0600 Position as before. Occasional light rain squalls. 0500-0600: noted frequent shifting of wind from E to W through S. Barometer dropping slowly. Excellent visibility.
0600-0800 Position as before. Light NW breeze. Barometer steady. Sky mostly overcast.
0800-1000 Parry (Elmer) Is., deep water pier. Sky overcast. Moderate rain. Northeasterly breeze.
1000-1200 Position as before. Wind diminishing. Barometer rising. Visibility about 6 mile due to rain.
1200-1400 Position as before. Visibility unlimited. Barometer falling. Thunderheads forming in S. Clearing in NE.
1400-1600 Position as before. Thunderheads remain in southerly direction. Clouds forming all over. Barometer falling.
1600-1800 Position as before. No change in weather.
1800-2000 Position as before. Thunderheads all around horizon. Visibility unlimited.
2000-2200 Position as before. Swells decreasing.
2200-2400 Position as before. Swells increasing.

PLACE: ENIWETOK-BIKINI BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 18 (Continued)

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/23	0200	Eniwetok	7	08-10	15	82	82	78		7	2	20					
	0400	Eniwetok	8	08-12	60	82	82	78		7	7	20	--	1			
	0600	Eniwetok	8	07-12	60	80	81	78		8	7	20					
	0800	Eniwetok	7	07-12	18	80	82	78		6	7	20	--	1			
	1000	Eniwetok	7	06-12	15	84	82	78		7	7	20	--	1			
	1200	Eniwetok	6	11-10	15	88	87	80		6	7	20	--	1			
	1400	Eniwetok	6	12-15	02	68	87	82		6	2	20	--	9			
	1600	Eniwetok	6	12-15	02	67	87	82		6	2	20	--	9			
	1800	Eniwetok	8	13-15	02	68	84	80		8	7	20	--	--			
	2000	Eniwetok	8	13-12	80	72	84	78		8	7	20	--	--			
	2200	Eniwetok						NO REPORTS									
	2400	Eniwetok						NO REPORTS									

LOG ENTRIES:

0000-0200 Moored, deep water cargo pier, Parry (Elmer) Is. Light rain squalls. Sky mostly overcast. Unlimited visibility except in squalls. Northeasterly breeze 10-12 knots. Barometer dropping slowly.
0200-0400 Moored as before. Light rain. Barometer steady. 10 to 12 miles visibility. Sky overcast.
0400-0600 Position as before. Frequent light rain squalls.
0600-0800 Vessel maneuvering off Parry (Elmer) Is. awaiting instructions to beach. Rain squalls to NE. Barometer steady. Excellent visibility.
0800-1000 Beached, old cargo pier, Parry (Elmer) Is. Heavy rain falling to northeastward approximately 12 miles away.
1000-1200 Position as before. Dark cumulonimbus clouds to northeastward. Occasional light rain falling.
1200-1400 Position as before. Barometer falling rapidly. Winds veering.
1400-1600 Position as before. Dark clouds to NE as before.
1600-1800 Position as before. Winds SE 15 knots. Visibility 10.0 miles. Barometer steady.
1800-2000 Position as before. Winds same as above. Barometer rising. Slight showers of rain.
2000-2200 Position as before. Occasional sprinkles of rain.
2200-2400 Position as before. Wind veering to south. Sky overcast.

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/24	0200	Eniwetok	6	16-12	01	77	83	78		6	2	20					
	0400	Eniwetok	2	14-08	01	76	83	78		2	2	20					
	0600	Eniwetok	1	14-05	01	75	82	78		1	2	20					
	0800	Eniwetok	7	14-05	05	80	83	79		5	2	20	4				
	1000	Eniwetok	6	11-05	15	84	86	80		5	2	20	4	1	11	--	--
	1200	Eniwetok						NO REPORTS									
	1400	Eniwetok						NO REPORTS									
	1600	Eniwetok						NO REPORTS									
	1800	Eniwetok	7	10-05	03	84	85	80		4	2	20	-	1			
	2000	Eniwetok	7	10-05	02	86	83	79		4	2	20	-	1			
	2200	Eniwetok	1	10-05	01	88	83	78		1	2	20	-	-			
	2400	Eniwetok						NO REPORTS									

LOG ENTRIES:

0000-0200 Moored and beached port side to, old cargo pier, Parry (Elmer) Is. Light south-southeasterly wind. Sky mostly overcast. Unlimited visibility. Barometer steady.

PLACE: ENIWETOK-BIKINI

BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 18 (Continued)

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/24																	

LOG ENTRIES:

0200-0400 Position as before. Sky clearing. Barometer steady.
0400-0600 Position as before. Sky mostly clear with cumulus clouds on horizon to easterly. Excellent visibility. Barometer steady.
0600-0800 Position as before. Sky becoming overcast with cumulus and thin altocumulus at various levels. Barometer rising. Unlimited visibility. Light southeasterly breeze.
0800-1000 At anchor: Lat 11°24.5'N-Long 162°22'E. Visibility excellent. Occasional light sprinkles of rain.
1000-1200 Position as before. Visibility excellent. 1000: heavy rain squall of about 10 minute duration. 1130: vessel commenced to roll in low NE swell.
1200-1400 Position as before. Visibility excellent. Low southerly swell. Low, short NE swell.
1400-1600 No entry
1600-1800 At Parry (Elmer) Is. Visibility unlimited. Barometer rising. Clear in E. Thunderheads in N.
1800-2000 Position as before. Weather same as above.
2000-2200 Position as before. Clouds diminishing. Visibility unlimited. Thunderheads in N.
2200-2400 Position as before. No change in weather.

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT.	C_L TYPE	C_L HT.	C_M	C_H	DD	PERIOD	HT.
8/25	0200	Eniwetok	3	10-05	03	86	82	78		3	2	20					
	0400	Eniwetok	2	10-08	01	82	82	78		2	2	20					
	0600	Eniwetok	3	10-05	03	86	83	78		3	2	20					
	0800	Eniwetok	6	09-05	03	86	84	79		4	2	20	7	--			
	1000	Eniwetok	4	09-03	01	86	86	80		4	2	20					
	1200	Eniwetok	4	09-Airs	02	86	88	80		4	2	20					
	1400	Eniwetok						NO	REPORTS								
	1600	Eniwetok						NO	REPORTS								
	1800	Eniwetok	6	Lt.Airs	03	75	87	79		4	2	20	9	2			
	2000	Eniwetok	6	Airs	16	78	83	78		6	7	20	--	--			
	2200	Eniwetok	6	Airs	80	78	83	78		6	7	20	--	--			
	2400	Eniwetok	4	Airs	01	78	--	78		4	2	20	--	--			

LOG ENTRIES:

0000-0200 Moored at old cargo pier, Parry (Elmer) Is., Eniwetok Atoll. Light southeasterly breeze. Visibility unlimited. Scattered cumulus clouds. Barometer dropping slowly.
0200-0400 Position as before. Weather unchanged in past 4 hours.
0400-0600 Position as before. Clouds becoming more developed. Unlimited visibility.
0600-0800 Position as before. Clouds becoming more developed. Barometer steady. Light easterly breeze.
0800-1000 Position as before. Cumulus clouds around horizon. Light breeze. Calm sea in lagoon. Barometer steady. Unlimited visibility.
1000-1200 Position as before. Weather unchanged.
1200-1400 Position as before. Visibility unlimited.
1400-1600 Position as before. Visibility unlimited. Calm, no swell.
1600-1800 Position as before. Visibility unlimited. No wind. Barometer steady. Thunderheads gathering all over.
1800-2000 Position as before. Heavy rain shower approaching from ENE direction.
2000-2200 Position as before. Slight rain shower.
2200-2400 Position as before. Barometer steady. Visibility unlimited. No wind.

PLACE: ENIWETOK-BIKINI

BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 18 (Continued)

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_W	TT_S	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/26	0200	Eniwetok	7	08-05	60	78	81	79		7	2	20					
	0400	Eniwetok	5	Lt.Airs	18	74	81	78		5	2	20					
	0600	Eniwetok	5	14-03	18	73	81	78		5	2	20					
	0800	Eniwetok	6	14-03	02	74	82	78		6	2	20					
	1000	Eniwetok	6	14-05	81	79	85	80		6	2	20					
	1200	Eniwetok	4	14-03		75	88	81		4	2	20					
	1400	Eniwetok	4	14-08	02	72	87	80		4	2	20					
	1600	Eniwetok	6	12-08	03	68	87	80		6	2	20					
	1800	Eniwetok	5	12-05	15	70	85	79		5	2	20					
	2000	Eniwetok	5	12-05	02	73	84	78		5	2	20					
	2200	Eniwetok	5	11-05	02	76	83	78		5	2	20					
	2400	Eniwetok						NO REPORTS									

LOG ENTRIES:

0000-0200 Moored and beached at old cargo pier, Parry (Elmer) Is. Sky mostly overcast with frequent rain squalls. Visibility 10-12 miles except in squalls. Barometer falling slowly. Light easterly airs.
0200-0400 Position as before. Sky clearing. Rain squalls around horizon. Light easterly airs.
0400-0600 Position as before. Visibility excellent.
0600-0800 Position as before. Visibility excellent. Calm, no swell.
0800-1000 Position as before. Visibility excellent.
1000-1200 Position as before. Sky clearing. Visibility excellent.
1200-1400 Position as before. Visibility excellent.
1400-1600 Position as before. Visibility excellent.
1600-1800 Position as before. Visibility excellent. Showers to northward.
1800-2000 Position as before. Visibility excellent.
2000-2200 Position as before. Visibility excellent.
2200-2400 Position as before. No change in weather conditions.

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_W	TT_S	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/27	0200	Eniwetok	8	10-08	60	74	81	78		7	2	20	1				
	0400	Eniwetok	6	09-05	18	74	82	78		6	2	20					
	0600	Eniwetok	4	09-05	01	74	82	78		4	2	20					
	0800	Eniwetok	3	10-08	01	74	83	78		3	2	20					
	1000	Eniwetok	4	13-10	80	78	82	79		4	2	20					
	1200	Eniwetok	4	12-10	02	76	86	80		4	2	20					
	1400	Eniwetok						NO REPORTS									
	1600	Eniwetok						NO REPORTS									
	1800	Eniwetok						NO REPORTS									
	2000	Eniwetok	2	12-10	01	78	83	80		2	2	20	--	--			
	2200	Eniwetok	2	12-10	02	78	83	80		2	2	20	--	--			
	2400	Eniwetok	2	12-10	02	78	83	80		2	2	20	--	--			

LOG ENTRIES:

0000-0200 Beached and moored, old cargo pier, Parry (Elmer) Is. Sky overcast. Light rain squalls. Gentle easterly breeze. Barometer steady. Excellent visibility except in rain squalls.

PLACE: ENIWETOK-BIKINI

BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 18 (Continued)

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/27																	

LOG ENTRIES:
0200-0400 Position as before. Squalls on horizon to N and W. Barometer steady. Sky clearing.
0400-0600 Position as before. Weather as before. Sky clearing. Barometer steady.
0600-0800 Position as before. Weather as before.
0800-1000 Position as before. Visibility reduced in showers.
1000-1200 Position as before. Visibility excellent.
1200-1400 Position as before. Visibility excellent.
1400-1600 Position as before. Visibility excellent.
1600-1800 Position as before. Visibility excellent.
1800-2000 Position as before. Visibility excellent.
2000-2200 Position as before. Visibility unlimited. Clouds diminishing. Barometer steady.
2200-2400 Position as before. No change in weather.

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/28	0200	Eniwetok	4	10-10	03	76	82	79		4	2	20					
	0400	Eniwetok	2	10-08	01	76	82	79		2	2	20					
	0600	Eniwetok	2	13-08	02	76	82	79		2	2	20					
	0800	Eniwetok	4	13-08	03	78	83	79		4	2	20					
	1000	Eniwetok	7	13-08	02	78	87	80		6	2	20	--	1			
	1200	Eniwetok	8	16-04	16	77	85	80		8	2	20	--	--			
	1400	Eniwetok	7	Airs	60	78	86	81		7	2	20	--	1			
	1600	Eniwetok	8	09-05	03	76	83	79		7	2	20	--	1			
	1800	11°24'N 162°39'E	8	07-15	02	80	81	78		8	2	20			07	5	3
	2000	11°23'N 162°56'E						N O		R E P	O R T	S					
	2200	11°25.0'N 163°13.0'E	8	07-15	80	90	82	78		8	7	20	--	--	07	5	3
	2400	11°25.0'N 163°32.0'E 090	1	07-15	01	90	82	78		1	2	20	--	--	07	5	3

LOG ENTRIES:
0000-0200 Beached and moored, old cargo pier, Parry (Elmer) Is. Moderate southeasterly wind 10-12 knots. Barometer steady. Partly overcast. Unlimited visibility.
0200-0400 Position as before. Sky clearing.
0400-0600 Position as before. Visibility unlimited. Low westerly swell.
0600-0800 Position as before. Visibility unlimited. Low westerly swell.
0800-1000 Position as before. Visibility unlimited. Thunderheads forming in the ENE.
1000-1200 Position as before. No change in weather.
1200-1400 Moored and beached as before. Light rain squalls. Good visibility. Barometer steady. Rain squalls on horizon to easterly and southerly.
1400-1600 Departing via deep entrance from Parry (Elmer) Is. Sky overcast. Thunderheads around horizon. Barometer steady. Light easterly breeze.
1600-1800 (1800 Position: Lat 11°24'N-Long 162°39'E) Visibility excellent. Low short NE swell.

PLACE: ENIWETOK-BIKINI — BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957 — TABLE 18 (Continued)

DATE	TIME	POSITION	COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/28																		

LOG ENTRIES:

1800-2000 (2000 Position: Lat 11°23'N-Long 162°56'E) Visibility excellent. Medium average NE swell. Slight NE sea.
2000-2200 (2200 Position: Lat 11°25.0'N-Long 163°13.0'E) En route Parry (Elmer) Is. to Bikini. Slight showers of rain. Visibility about 10.0 miles. Easterly sea (slight). Sky overcast. Barometer rising. 2310: lightning in the east. Long bright flashes.
2200-2400 (2400 Position: Lat 11°25.0'N-Long 163°32.0'E - on course 090° true) Thunderheads and lightning in the E. Visibility unlimited. Barometer steady.

DATE	TIME	POSITION	COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/29	0200	11°25'N 163°49'E	090	3	10-10	01	86	82	78	85	3	2	20			10	5	3
	0400	11°25.5'N 164°07'E	090	4	10-12	03	86	82	78	85	4	2	20			10	5	3
	0600	11°25'N 164°25'E	090	2	06-10	01	83	83	79		2	2	20			06	4	3
	0800	11°25'N 164°43'E							N O		R E P	O R	T S					
	1000	11°24.0'N 165°00'E	087	4	07-10	03	86	84	80		3	2	20	--	1	07	4	3
	*1200	Bikini	085	4	07-10	02	87	85	79		3	2	20	--	1	07	4	3
	1400	Bikini		4	06-12	02	86	85	79		3	2	20	--	1	--	--	-
	1600	Bikini		5	05-12	03	85	86	80		5	2	20	--	--	--	--	-
	1800	Bikini		5	07-12	02	83	84	79		5	2	20					
	2000	Bikini		2	06	01	85	83	78		2	2	20					
	2200	Bikini		2	06-12	02	86	83	79		2	2	20	--	--	--	--	-
	2400	Bikini							N O		R E P	O R	T S					

LOG ENTRIES:

0000-0200 (0200 Position: Lat 11°25'N-Long 163°49'E) Sky clearing. Cumulus clouds to S. Barometer dropping slowly. Unlimited visibility. Light southeasterly wind and sea.
0200-0400 (0400 Position: Lat 11°25.5'N-Long 164°07'E) No change in weather for past 4 hours.
0400-0600 (0600 Position: Lat 11°25'N-Long 164°25'E) Visibility excellent. Slight ENE sea. Moderate average NE swell.
0600-0800 (0800 Position: Lat 11°25'N-Long 164°43'E) Visibility excellent. Slight northeasterly sea. Moderate average NE swell.
0800-1000 (1000 Position: Lat 11°24.0'N-Long 165°00'E) Visibility unlimited. Thunderheads all around horizon. Cirrus clouds overhead.
*1000-1200 (1200 Position: Approaching Bikini Atoll) No change in weather.
1200-1400 Moored at Enyu Is., Bikini Atoll. Moderate NE wind 12-15 knots. Unlimited visibility. Rain squalls in distance around horizon. Barometer steady.
1400-1600 Position as before. Weather as before. Rain squalls to easterly.
1600-1800 Position as before. Visibility excellent.
1800-2000 Position as before. Visibility excellent.
2000-2200 Position as before. Visibility unlimited. Barometer rising. Thunderheads around horizon. Northeasterly breeze.

PLACE: ENIWETOK-BIKINI

BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 18 (Continued)

DATE	TIME	POSITION	COURSE	N8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/29																		

LOG ENTRIES: 2200-2400 Position as before. No change in weather.

DATE	TIME	POSITION	COURSE	N8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/30	0200	Bikini		4	06-10	03	84	82	79		4	2	20					
	0400	Bikini		6	06-10	03	82	82	79		6	2	20					
	0600	Bikini		4	06-10	01	78	82	78		4	2	20					
	0800	Bikini		4	06-10	02	75	83	79		4	2	20					
	1000	Bikini		3	10-10	02	73	85	80		2	2	20	--	1			
	1200	Bikini		3	07-10	81	73	86	80		2	2	20	--	1			
	*1400	Bikini	253	3	08-10	02	78	87	81		2	2	20	--	1			
	1600	11°26'N 165°09'E	270	4	08-10	03	80	87	81		4	2	20					
	1800	11°25'N 164°51'E	270	4	07-10	02	72	91	83		4	2	20	--	1	07	3	2
	2000	11°25'N 164°34'E							N O	R E	P O	R T	S					
	2200	11°26.0'N 164°16.5'E	270	3	07-10	16	85	85	80		3	2	20	--	-	07	3	2
	2400	11°26.0'N 164°00.0'E	270	3	07-10	16	85	85	80		3	2	20	--	-	07	3	2

LOG ENTRIES:

0000-0200 Moored to LST cargo pier, Bikini Atoll. Sky partly overcast. Excellent visibility. Barometer dropping slowly. Light east-northeasterly wind.
0200-0400 Position as before. No change in weather past 4 hours except sky becoming more overcast.
0400-0600 Position as before. Visibility excellent.
0600-0800 Position as before. Visibility excellent.
0800-1000 Position as before. Visibility unlimited. Barometer falling. Thunderheads all around horizon. Cirrus clouds overhead. 1100: moderate rain shower from ENE direction.
1000-1200 Position as before. Visibility unlimited. Moderate rain showers.
*1200-1400 (1400 Position: Departing Bikini) Moderate easterly wind and sea. Unlimited visibility. Thunderheads around horizon. Sky overhead clear. Barometer rising slowly.
1400-1600 (1600 Position: Lat 11°26'N-Long 165°09'E) No change in weather past 4 hours.
1600-1800 (1800 Position: Lat 11°25'N-Long 164°51'E) Visibility excellent.
1800-2000 (2000 Position: Lat 11°25'N-Long 164°34'E) Visibility excellent. Low NE swells.
2000-2200 (2200 Position: Lat 11°26.0'N-Long 164°16.5'E - course 270° true - 8.85 fon speed) Visibility unlimited. Cumulus clouds all around horizon. Barometer rising. Lightning (Moderate) in S.
2200-2400 (2400 Position: Lat 11°26.0'N-Long 164°00.0'E) No change in weather.

DATE	TIME	POSITION	COURSE	N8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/31	0200	11°26'N 163°42'E	270	4	08-12	03	82	84	80		4	2	20			08	4	2
	0400	11°26'N 163°24'E	270	4	07-12	02	80	85	80		4	2	20			07	4	2

PLACE: ENIWETOK-BIKINI — BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957 — TABLE 18 (Continued)

DATE	TIME	POSITION/COURSE		N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
8/31	0600	11°27'N 163°06'E	270	4	07-15	02	78	83	79		4	2	20			07	4	2
	0800	11°25'N 162°51'E	267	4	07-15	15	78	83	79		4	2	20			07	4	2
	*1000	Eniwetok	267	6	09-10	03	80	90	82		3	2	20	--	1	09	4	2
	1200	Eniwetok		6	10-10	02	84	87	80		3	2	20	--	1			
	1400	Eniwetok		4	09-10	01	78	88	80		4	2	20					
	1600	Eniwetok		4	09-10	02	74	88	81		4	2	20					
	1800	Eniwetok		4	10-10	02	75	86	80		4	2	20					
	2000	Eniwetok		4	10-10	02	80	84	78		4	2	20					
	2200	Eniwetok		3	10-10	02	82	83	78		3	2	20					
	2400	Eniwetok		4	10-10	81	84	82	79		4	7	20	--	--			

LOG ENTRIES:

0000-0200 (0200 Position: Lat 11°26'N-Long 163°42'E - Bikini to Parry (Elmer) Is.) Sky cloudy around horizon. Unlimited visibility. Light northeasterly wind and sea. Light rain squalls noted passing to S of vessel. Lightning flashes to W.

0200-0400 (0400 Position: Lat 11°26'N-Long 163°24'E) Bright lightning flashes to NW. Barometer dropping slowly. No change in weather for past 4 hours.

0400-0600 (0600 Position: Lat 11°27'N-Long 163°06'E) Visibility excellent. Moderate NE swell.

0600-0800 (0800 Position: Lat 11°25'N-Long 162°51'E) Visibility excellent. Low NE swell.

*0800-1000 (1000 Position: Approaching Parry (Elmer) Is.) Visibility unlimited. Easterly breeze. High cirrus clouds blown in streaks. Thunderheads all around horizon.

1000-1200 Position: Parry (Elmer) Is. No change in weather.

1200-1400 Beached and moored at Parry (Elmer) Is. Cumulus clouds around horizon. Light easterly breeze. Unlimited visibility. Barometer dropping slowly.

1400-1600 Position as before. No change in weather.

1600-1800 Position as before. Visibility excellent.

1800-2000 Position as before. Visibility excellent.

2000-2200 Position as before. Visibility unlimited. Barometer rising. Light easterly breeze. Cumulus clouds around horizon.

2200-2400 Position as before. Rain showers. Visibility about 8 miles in the E. Unlimited elsewhere. Barometer rising.

DATE	TIME	POSITION/COURSE		N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
9/1	0200	Eniwetok		3	10-08	02	82	81	79		3	2	20					
	0400	Eniwetok		4	10-08	03	80	82	79		4	2	20					
	0600	Eniwetok		4	10-10	02	82	81	78		4	2	20					
	0800	Eniwetok		6	11-10	03	84	82	79		6	2	20					
	1000	Eniwetok		4	15-10	01	86	85	81		4	2	20	6	1			
	1200	Eniwetok		4	15-10	02	88	86	80		4	2	20	6	1			
	1400	Eniwetok		4	11-10	02	80	87	80		4	2	2C	6	1			
	1600	Eniwetok							N O		R E P	O R	T S					
	1800	Eniwetok		6	10-10	03	84	84	80		3	2	20	6	1			
	2000	Eniwetok		3	10-10	01	86	83	79		3	2	20	--	--			

PLACE: ENIWETOK-BIKINI BI-HOURLY OBSERVATIONS, MSTS - T-LST 618, AUGUST 18 - SEPTEMBER 1, 1957

TABLE 18 (Concluded)

DATE	TIME	POSITION/COURSE	N_8	DDFF	WX	P	TT	TT_w	TT_s	C_L AMT. 8ths	C_L TYPE	C_L HT. 00 ft.	C_M	C_H	WAVES DD	WAVES PERIOD	WAVES HT. ft.
9/1	2200	Eniwetok	3	10-10	02	90	83	79		3	2	20	--	--			
	2400	Eniwetok	2	10-10	02	90	83	79		2	2	20	--	--			

LOG ENTRIES:

0000-0200 Beached and moored at Parry (Elmer) Is. Towering cumulus clouds around horizon. Light southeasterly breeze. Excellent visibility. Barometer steady.

0200-0400 Position as before. No change in weather.

0400-0600 Position as before. Sky partly overcast with cumulus clouds. Unlimited visibility. Light southeasterly wind. Barometer steady.

0600-0800 Position as before. No change in weather for past 8 hours with exception of sky becoming more overcast.

0800-1000 Position as before. Visibility excellent.

1000-1200 Position as before. Visibility excellent. Low SW swell.

1200-1400 Position as before. Visibility excellent.

1400-1600 Position as before. Visibility excellent.

1600-2000 Position as before. No change in weather.

2000-2200 Position as before. No change in weather.

2200-2400 Position as before. No change.

Part C. Observational Data, Second Intensive Phase (January 25 -- February 8, 1958)

NOTES: TABLES 19-32

TABLE 19. FRED: HOURLY OBSERVATIONS AND DAILY SUMMARY.

See Notes for Table 4, pp. 39f.

TABLE 20. FRED: RAWINSONDE OBSERVATIONS.

See Notes for Table 5, p. 41.

TABLE 21. BRUCE: THREE-HOURLY OBSERVATIONS.

See Notes for Table 6, pp. 41-43, as well as the note below.

Experienced observers made the observations at BRUCE during the following interval (times are inclusive): 1200 Jan 25 -- 0900 Jan 27.

TABLE 22. BRUCE: HOURLY RELATIVE HUMIDITIES.

See Notes for Table 9, p. 44.

TABLE 23. BRUCE AND KEITH: SPECIAL OBSERVATIONS.

TT_s BRUCE. These measurements were made with an unshielded mercury-in-glass thermometer graduated to half-degrees C. Readings were taken with the thermometer bulb at a depth of 1 to 6 inches beneath the surface of the water, with the reading being made to the nearest tenth of a degree C. at that time when the mercury column had become steady at a minimum value. Mean values of the several observations were converted to °F. in each instance and are estimated to be correct within 0.2°F. in 9 out of 10 instances and within 0.5°F. in all instances (see Notes for Table 7, pp. 43-44, and note that the mean based on several observations will be somewhat more accurate than any single observation).

TT_s KEITH values were read with the same type of thermometer described immediately above, with the bulb at depths of 3-6 inches. Values were, however, read only to the nearest half-degree. Values given represent a mean of several readings as shown and are accurate within 0.3° C.

TT and TT_w were measured with an Asmann psychrometer (graduated in whole degrees F.), were read to the nearest 0.5°F., and are correct within 0.4°F. Heights are correct within 6 inches.

TABLE 24. KEITH: THREE-HOURLY OBSERVATIONS.

See Notes for Table 6, pp. 41-43, as well as the note below.

Experienced observers made the observations at KEITH during the following interval (times are inclusive): 1200 Jan 25 -- 0900 Feb 4.

TABLE 25. KEITH: HOURLY RELATIVE HUMIDITIES.

See Notes for Table 9, p. 44.

TABLE 26. MACK: DAILY OBSERVATIONS.

See Notes for Table 10, pp. 44-45, as well as note below.

Experienced observers made the observations at MACK on the following dates: Jan 26-30 (inclusive); Feb 3, 6, 7.

TT on Jan 25-29 (inclusive) was obtained from max and min thermometers after re-setting. Values are correct within 0.5° F.

TABLE 27. MACK: BI-HOURLY TEMPERATURES AND RELATIVE HUMIDITIES.

See Notes for Table 11, p. 45.

TABLE 28. ELMER: DAILY OBSERVATIONS.

See Notes for Table 12, p. 46, as well as note below.

Experienced observers made the observations at ELMER on the following dates: Jan 26 - Feb 2 (inclusive); Feb 4, 5.

TABLE 29. JANET AND YVONNE: DAILY RAINFALL.

RR is accurate to 0.01 inch.

Time is accurate to within 5 minutes.

TABLE 30. ELMER-MACK: LAGOON TRAVERSES.

See Notes for Table 15, pp. 46-47, as well as notes below.

LOCATIONS by Zones are in doubt as follows: 1330, Jan 25 observation is near Zone 3, and may be a few hundred yards within that zone; 1345, Jan 27 observation may also be just within Zone 3; 1338, Jan 29, may also be just within Zone 3; 1344, Feb 6, may be up to a few hundred yards within Zone 2.

TT from Jan 25 through Jan 29 was obtained from same thermometer used for TT_s (Fahrenheit thermometer graduated in tenths of a degree F.) and are correct within 0.2° F. where read to the nearest tenth and within 0.4° F. where read to the nearest 0.5° F.

TABLE 31. BETWEEN BRUCE, KEITH, ELMER: LAGOON TRAVERSES.

See Notes for Table 16, pp. 47-48.

TABLE 32. LAGOON-OCEAN: LAGOON-OCEAN TRAVERSES.

See Notes for Table 17, p. 48.

PLACE: FRED

HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
1/25	0058	965	80.0	75.0	79	1	1CuE25	0	0	0	1	ENE14				
	0157	960	79.7	74.2	77	0	0	0	0	0	0	ENE12				
	0259	960	79.7	74.2	77	0	0	0	0	0	0	ENE13				
	0358	955	79.7	74.2	77	0	0	0	0	0	0	ENE16				
	0457	950	80.0	74.2	76	0	0	0	0	0	0	NE18				
	0559	950	80.0	74.2	76	0	0	0	0	0	0	NE14				
	0656	960	78.4	74.0	81	7	7ScE25e	0	0	0	7	NE14	0644-0655			
	0759	970	77.3	74.8	89	5	1ScE15	4CuE25	0	0	5	NE15	0725-0732			
	0858	980	79.9	75.3	81	3	3CuE25	0	0	0	3	ENE16				
	0957	995	81.7	76.1	77	4	2CuE25	2Ac 80	0	0	4	ENE18				
	1059	000	82.3	76.6	77	3	3CuE25	0	0	0	3	ENE18				
	1158	995	82.0	75.8	75	3	3CuE25	0	0	0	3	ENE18				
	1257	980	85.1	77.0	69	4	4CuE25	0	0	0	4	ENE17				
	1358	960	83.3	76.2	72	3	3CuE25	0	0	0	3	ENE15				
	1456	940	83.8	76.4	71	1	1CuE20	0	0	0	1	ENE16				
	1559	920	83.6	76.3	72	2	1CuE20	1Ac 80	0	0	2	ENE16				
	1659	920	81.5	77.0	82	3	3CuE20	0	0	0	3	ENE16				
	1755	920	82.3	75.4	73	3	3CuE20	0	0	0	3	ENE16				
	1859	920	81.3	75.6	82	2	2CuE20	0	0	0	2	ENE16				
	1958	945	80.2	75.2	79	2	2CuE21	0	0	0	2	ENE15				
	2058	950	79.8	74.6	79	7	7CuE22e	0	0	0	7	ENE15				
	2157	960	79.8	74.8	80	4	4CuE22	0	0	0	4	ENE16				
	2255	960	79.4	74.1	78	3	3CuE21	0	0	0	3	ENE17				
	2355	960	79.4	74.3	79	2	2CuE21	0	0	0	2	NE17		85	77	T
1/26	0058	960	79.7	74.3	83	2	2CuE21	0	0	0	2	ENE18				
	0159	950	79.3	74.4	80	0	0	0	0	0	0	ENE16				
	0256	940	79.0	74.5	81	0	0	0	0	0	0	ENE16				
	0356	935	78.9	74.5	81	0	0	0	0	0	0	ENE16				
	0459	930	78.4	75.0	85	0	0	0	0	0	0	ENE15				
	0556	940	78.4	75.0	85	0	0	0	0	0	0	ENE18				
	0656	950	78.2	75.1	87	3	3CuE25	0	0	0	3	ENE19				
	0759	960	78.6	72.9	76	8	2CuE25	6Cs	0	0	3	NE17				
	0858	970	80.0	72.8	72	8	2CuE25	6Cs	0	0	3	NE16				
	0957	990	82.8	73.0	63	8	2CuE25	6Cs	0	0	3	NE17				
	1059	000	83.3	74.3	66	8	2CuE25	6Cs	0	0	3	NE17				
	1158	990	83.1	74.4	66	8	2CuE25	6Cs	0	0	3	NE15				
	1257	970	84.9	74.8	62	5	3CuE25	2Cs	0	0	5	NE15				
	1359	940	84.4	74.2	62	5	3CuE25	2Cs	0	0	5	NE16				
	1458	925	84.7	74.1	61	8	1CuE25	7Cs	0	0	4	NE15				
	1557	910	82.9	75.2	70	7	1CuE25	6Cs	0	0	2	NNE15				
	1658	900	82.2	75.0	72	6	2CuE25	5Cs	0	0	3	NNE14				
	1755	885	82.0	74.2	70	6	2CuE25	6Cs	0	0	3	NNE15				

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HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19
(Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
1/26	1856	885	80.2	74.0	75	4	4CuE21	0	0	0	4	NE14				
	1958	890	80.0	74.0	75	3	3CuE21	0	0	0	3	NE16				
	2055	900	79.8	73.6	75	2	2CuE21	0	0	0	2	NE16				
	2155	910	79.6	73.0	73	0	0	0	0	0	0	NE19				
	2256	910	79.4	72.5	72	0	0	0	0	0	0	NE20				
	2355	920	79.1	73.1	73	0	0	0	0	0	0	NE21		85	78	0
1/27	0059	915	79.1	73.1	75	0	0	0	0	0	0	NE21				
	0158	905	79.0	73.0	75	0	0	0	0	0	0	NE22				
	0256	895	78.8	73.8	79	0	0	0	0	0	0	NE22				
	0359	885	78.8	73.8	79	0	0	0	0	0	0	NE20				
	0458	885	78.6	73.7	79	0	0	0	0	0	0	NE22				
	0556	870	78.8	73.8	79	0	1CuE25	0	0	0	0	NE22				
	0656	870	79.0	73.0	75	1	1CuE25	0	0	0	1	NE24				
	0757	870	79.0	72.0	71	1	1CuE25	0	0	0	1	ENE16				
	0859	875	80.0	72.0	68	1	1CuE25	0	0	0	1	ENE22				
	0958	890	81.8	72.4	64	1	1CuE25	0	0	0	1	ENE18				
	1058	895	83.3	74.2	65	1	1CuE25	0	0	0	1	ENE18				
	1159	905	84.4	74.0	61	1	1CuE25	0	0	0	1	ENE22				
	1257	880	83.4	73.4	62	1	1AcE80	0	0	0	1	ENE18				
	1358	855	83.4	73.4	62	1	1CuE25	0	0	0	1	E18				
	1459	840	83.1	74.1	63	3	1CuE25	2AcE80	0	0	3	E18				
	1557	825	83.4	73.4	62	3	3CuE25	0	0	0	3	E20				
	1658	825	82.9	72.9	63	8	1CuE25	7Cs	0	0	3	ENE16				
	1756	845	83.1	73.0	62	8	1CuE25	7Cs	0	0	3	ENE18				
	1859	850	80.1	71.9	67	8	1CuE25	7Cs	0	0	3	ENE14				
	1958	870	79.8	71.7	68	7	1CuE25	6Cs	0	0	3	ENE16				
	2058	885	79.9	71.4	66	1	1CuE25	0	0	0	1	ENE16				
	2157	890	79.6	71.5	67	1	1CuE25	0	0	0	1	ENE18				
	2259	900	79.7	72.6	71	3	3CuE25	0	0	0	3	ENE16				
	2359	910	79.6	72.6	71	5	5CuE25	0	0	0	5	ENE16		84	79	0
1/28	0058	905	79.1	71.9	71	0	0	0	0	0	0	NNE16				
	0157	905	78.9	71.9	71	0	0	0	0	0	0	NNE16				
	0255	890	78.9	71.5	70	0	0	0	0	0	0	NNE16				
	0357	875	78.9	71.5	70	0	0	0	0	0	0	NE18				
	0458	870	78.0	71.7	73	2	2CuE21	0	0	0	2	NNE15	0438-0442			
	0555	865	78.0	71.6	73	2	2CuE21	0	0	0	2	NNE16				
	0657	870	78.0	71.6	73	1	1CuE25	0	0	0	1	NNE16				
	0758	880	78.6	71.0	69	4	1CuE25	3Ci	0	0	1	NNE14				
	0859	890	79.7	72.2	70	4	1CuE25	3Ci	0	0	1	NNE16				
	0958	905	82.1	72.1	62	4	1CuE25	3Ci	0	0	1	E14				
	1057	910	82.2	73.0	65	4	1CuE25	3Ci	0	0	1	E14				

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HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19
(Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
1/28	1159	895	83.2	73.2	62	4	1CuE25	3Ci	0	0	1	E12				
	1258	865	84.2	72.2	56	4	1CuE25	3Ci	0	0	1	ENE17				
	1357	835	85.0	73.5	58	3	1CuE25	2Ci	0	0	1	E14				
	1459	820	84.1	73.2	60	3	1CuE25	2Ci	0	0	1	E16				
	1557	800	84.1	73.2	60	3	1CuE25	2Ci	0	0	1	E16				
	1658	795	82.0	72.8	65	1	1CuE25	0	0	0	1	ENE14				
	1759	800	82.4	73.6	66	0	0	0	0	0	0	E13				
	1856	810	80.5	72.7	69	0	0AcNE100	0	0	0	0	E13				
	1959	830	80.4	72.6	69	0	0	0	0	0	0	E14				
	2058	850	80.0	73.1	72	0	0	0	0	0	0	E15				
	2159	860	80.1	71.0	64	0	0	0	0	0	0	E16				
	2257	870	79.8	72.4	70	1	1CuE25	0	0	0	1	ENE15				
	2359	870	79.4	72.6	72	3	3CuE25	0	0	0	3	ENE13		85	78	T
1/29	0056	855	79.1	72.5	73	2	2CuE21	0	0	0	2	ENE15				
	0158	850	79.2	73.1	75	2	2CuE21	0	0	0	2	E16				
	0255	850	79.1	72.8	74	2	2CuE21	0	0	0	2	E16				
	0355	845	78.8	74.8	83	3	3CuE21	0	0	0	3	E15				
	0458	845	78.8	74.6	82	2	2CuE21	0	0	0	2	E15				
	0555	845	78.8	74.8	82	2	2CuE21	0	0	0	2	E14				
	0659	845	79.0	74.5	81	3	2CuE21	6Cs	0	0	2	E16				
	0758	850	79.3	74.8	81	3	3CuE21	0	0	0	3	E18				
	0857	865	80.3	75.0	78	3	3CuE21	0	0	0	3	E19				
	0958	880	82.2	75.5	73	2	2CuE21	0	0	0	2	E15				
	1056	885	82.1	75.5	73	2	2CuE21	0	0	0	2	E16				
	1156	865	82.8	75.0	70	2	2CuE21	0	0	0	2	E13				
	1258	845	83.0	75.1	69	2	2CuE21	0	0	0	2	E14				
	1359	815	85.1	77.0	70	2	1CuE21	1Ci	0	0	1	E14				
	1456	795	84.8	77.1	73	2	1CuE21	1Ci	0	0	1	E12				
	1559	770	84.3	77.6	74	3	3CuE21	0	0	0	3	E13				
	1657	765	84.0	76.0	69	3	3CuE25	0	0	0	3	E16				
	1759	790	84.0	76.0	69	3	3CuE25	0	0	0	3	ENE14				
	1858	800	81.3	75.2	75	3	2CuE25	1Ac 80	0	0	3	ENE15				
	1957	810	80.5	75.0	81	3	3CuE25	0	0	0	3	E14				
	2059	820	80.5	75.0	81	2	2CuE25	0	0	0	2	ENE14				
	2158	840	80.2	75.0	79	2	2CuE25	0	0	0	2	ENE16				
	2257	840	80.2	75.0	79	2	2CuE25	0	0	0	2	ENE16				
	2359	840	80.2	75.0	79	2	2CuE25	0	0	0	2	ENE17		85	79	0
1/30	0058	840	78.3	73.0	77	4	4CuE25	0	0	0	4	NE12				
	0159	840	77.4	73.2	83	4	4CuE25	0	0	0	4	NNE12				
	0257	830	77.1	73.0	83	2	2CuNE25	0	0	0	2	NNE18				
	0358	820	77.2	73.1	83	2	2CuNE25	0	0	0	2	NNE11				

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HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19 (Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
1/30	0456	810	77.2	73.4	85	1	1CuNE25	0	0	0	1	NNE10				
	0559	800	76.8	74.7	90	1	1CuNE25	0	0	0	1	NNE11				
	0659	800	76.9	74.7	90	8	2CuNE25	6Ac 80e	0	0	8	ENE10				
	0759	810	78.0	69.8	67	8	2CuE25	6Ac 80e	0	0	5	NNE8				
	0856	825	79.1	75.0	83	8	2CuE25	6Ac 80e	0	0	5	ENE9				
	0957	840	81.2	76.0	80	3	1CuE25	2Ac 80	0	0	2	E9				
	1056	850	83.1	76.8	75	2	2Cs	0	0	0	1	E10				
	1158	845	84.2	78.6	78	5	2CuE25	1Ac 100	2Cs	0	4	E12				
	1259	825	85.0	78.8	74	5	2CuE25	3Cs	0	0	2	E8				
	1359	805	84.6	78.6	76	5	2CuE25	3Cs	0	0	2	E8				
	1456	785	86.0	78.0	70	8	2CuE25	6Cs	0	0	3	E10				
	1558	765	85.8	78.1	70	5	2CuE25	3Cs	0	0	2	E8				
	1658	765	85.3	78.2	73	2	2CuE25	0	0	0	2	E8				
	1759	780	84.0	78.0	76	2	2CuE25	0	0	0	2	E12				
	1857	800	81.0	76.5	81	2	2CuE25	0	0	0	2	E10				
	1958	810	80.8	76.0	79	2	2CuE25	0	0	0	2	E14				
	2059	815	80.8	76.0	79	2	2CuE25	0	0	0	2	E12				
	2157	830	80.0	75.0	79	2	2CuE25	0	0	0	2	E14				
	2258	840	80.2	76.5	84	6	6AcE80e	0	0	0	6	E14				
	2359	855	80.2	76.5	84	8	8AcE80e	0	0	0	8	E15		86	77	0
1/31	0058	855	80.3	76.2	84	8	8Ac 80e	0	0	0	8	E16				
	0159	855	80.1	76.1	83	8	8Ac 80e	0	0	0	8	E16				
	0258	850	79.6	75.8	84	8	2CuE25	6Ac 80e	0	0	8	E14				
	0356	840	79.5	75.6	83	4	2CuE25	2Ac 80	0	0	4	E13				
	0457	830	79.4	75.3	83	2	1CuE25	1Ac 80	0	0	2	E14				
	0559	800	78.4	75.6	88	2	2CuE25	0	0	0	2	E12				
	0658	805	79.2	75.2	83	2	2CuE21	0	0	0	2	E13				
	0757	810	79.8	75.0	80	2	2CuE21	0	0	0	2	E14				
	0855	825	80.2	75.2	79	2	2CuE21	0	0	0	2	E14				
	0959	845	82.2	76.2	76	2	2CuE21	0	0	0	2	E14				
	1058	855	83.5	76.2	71	2	2CuE20	0	0	0	2	E14				
	1159	845	83.9	77.8	76	4	4CuE21	0	0	0	4	E14				
	1258	835	83.5	78.4	80	5	5CuE21	0	0	0	5	E15	1245-1250			
	1358	825	84.3	77.8	75	4	4CuE21	0	0	0	4	E14	1315-1321			
	1455	795	82.6	76.9	78	10	3CuE21	10Cs	0	0	3	E11				
	1558	780	84.1	76.8	72	10	3CuE21	10Cs	0	0	3	E14				
	1656	780	83.9	77.0	73	3	3CuE21	0	0	0	3	ENE17				
	1756	790	83.6	76.9	74	3	3CuE21	0	0	0	3	E16				
	1859	810	81.0	76.0	80	3	3CuE21	0	0	0	3	E18				
	1958	825	80.4	75.3	80	1	1CuE21	0	0	0	1	E18				
	2056	830	80.0	76.0	83	3	3CuE21	0	0	0	3	E16				
	2159	840	80.1	76.1	83	3	3CuE21	0	0	0	3	E15				

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HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19 (Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
1/31	2256	850	80.0	76.0	83	4	4CuE21	0	0	0	4	E16				
	2356	845	79.9	76.2	84	4	4CuE21	0	0	0	4	E20		84	78	T
2/1	0058	845	79.9	76.2	84	3	3CuE25	0	0	0	3	E20				
	0157	830	79.8	75.2	82	2	2CuE25	0	0	0	2	E20				
	0259	815	79.8	75.2	82	1	1CuE25	0	0	0	1	E18				
	0357	795	79.8	75.2	82	1	1CuE25	0	0	0	1	E18				
	0458	775	79.8	75.5	82	0	0	0	0	0	0	E20				
	0559	810	79.8	75.5	82	0	0	0	0	0	0	E20				
	0659	810	79.8	75.2	81	2	2CuE25	0	0	0	2	E16				
	0758	830	80.0	75.0	79	6	6CuE21e	0	0	0	6	E18				
	0856	850	80.2	76.0	82	6	3CuE21	3AsE100e	0	0	6	E16	0814-0819			
	0956	870	82.0	75.8	75	6	3CuE21	3AsE100e	0	0	6	E20				
	1058	885	81.6	76.8	81	7	3CuE21	1ScE25	3As 100e	0	7	E20				
	1158	885	83.0	76.0	73	3	3CuE21	0	0	0	3	E22				
	1259	860	84.2	76.0	68	0	0	0	0	0	0	E16				
	1356	840	84.3	76.2	68	1	1AcE100	0	0	0	1	E16				
	1457	820	84.2	76.1	68	0	0	0	0	0	0	E15				
	1558	805	84.6	77.6	73	1	1CuE20	0	0	0	1	ENE16				
	1657	800	84.7	77.7	73	1	1CuE20	0	0	0	1	ENE18				
	1756	805	84.4	77.5	73	1	1CuE20	0	0	0	1	ENE16				
	1856	825	82.2	76.0	75	2	2CuE20	0	0	0	2	ENE18				
	1958	840	80.3	75.0	78	2	2CuE20	0	0	0	2	ENE16				
	2056	855	80.4	75.0	77	4	4CuE20	0	0	0	4	ENE15				
	2159	865	80.0	75.0	79	3	3CuE20	0	0	0	3	ENE18				
	2259	870	78.3	75.8	89	10	10ScE21e	Unknown	Unknown	Unknown	10	E15	2245-2253			
	2358	870	78.3	75.8	89	7	2ScE21e	0	0	0	7	ENE21	2258-2325	85	78	0.04
2/2	0057	870	78.3	75.8	89	2	2CuE25	0	0	0	2	E15				
	0158	860	79.1	76.1	87	8	8CuE25e	0	0	0	8	E16	0157-0304			
	0259	855	78.0	75.5	89	8	8CuE25e	0	0	0	8	ENE18				
	0356	845	78.0	75.5	89	10	10CuE25e	Unknown	Unknown	Unknown	10	ENE20	0355-0403			
	0458	840	78.8	75.4	85	8	8CuE25e	0	0	0	8	ENE19				
	0557	845	79.4	75.4	81	8	8CuE25e	0	0	0	8	ENE16				
	0658	845	79.4	75.4	81	8	8CuE25e	0	0	0	8	ENE20				
	0759	850	79.7	75.5	83	5	3CuE25	2Ac 80	0	0	5	NE20				
	0858	870	80.3	75.7	81	5	3CuE25	2Ac 80	0	0	5	NE20				
	0957	900	78.1	75.8	89	9	1ScE15	2CuE25	6Ac 80e	0	9	ENE22	0927-0956			
	1059	905	80.2	77.1	87	9	1ScE15	2CuE25	6Ac 80e	0	9	ENE22	1025-1034			
	1158	905	80.1	76.3	84	9	1ScE15	2CuE25	6Ac 80e	0	9	ENE20				
	1259	885	80.1	76.2	84	9	1ScE15	2CuE25	6Ac 80e	0	9	ENE20				
	1358	870	80.3	76.4	83	8	2CuE25	6Ac 80e	0	0	8	E18				
	1458	840	81.7	76.6	80	8	2CuE25	6Ac 80e	0	0	8	ENE17				

PLACE: FRED

HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19
(Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_0	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
2/2	1559	825	82.9	75.6	72	8	2CuE25	6Ac 80e	0	0	8	NE22				
	1658	820	82.6	75.0	71	8	3CuE22	7AsE70e	0	0	8	NE24				
	1755	825	82.0	75.0	72	8	3CuE22	7AsE70e	0	0	8	NE25				
	1859	830	81.2	74.5	73	6	2CuE22	6AcE70e	0	0	6	NE24				
	1958	825	80.0	73.2	72	2	2CuE22	0	0	0	2	NE24				
	2056	835	79.9	74.0	75	2	2CuE22	0	0	0	2	ENE26				
	2157	845	79.9	73.5	74	2	2CuE22	0	0	0	2	ENE24				
	2258	850	79.5	73.5	75	2	2CuE21	0	0	0	2	ENE24				
	2355	845	79.4	73.5	75	2	2CuE21	0	0	0	2	ENE23		83	78	0.05
2/3	0059	845	79.3	74.0	78	5	5CuE25	0	0	0	5	ENE22				
	0159	840	79.2	74.0	78	5	5CuE25	0	0	0	5	ENE24				
	0256	830	79.0	73.9	78	2	2CuE25	0	0	0	2	ENE24				
	0359	830	78.8	73.8	79	2	2CuE25	0	0	0	2	ENE24				
	0459	815	78.8	73.9	80	2	2CuE25	0	0	0	2	ENE21				
	0556	810	78.8	73.9	80	2	2CuE25	0	0	0	2	ENE18				
	0659	810	79.2	74.1	79	5	5CuE25	0	0	0	5	NE18				
	0759	825	79.4	74.6	80	8	2CuE25	6Ac 80e	0	0	8	ENE20				
	0858	850	79.9	74.8	79	3	3CuE25	0	0	0	3	ENE19	0818-0829			
	0959	860	80.4	75.0	78	8	6CuE25e	2Ac 80	0	0	8	ENE16	0942-0949			
	1058	870	82.3	76.6	77	8	6CuE25e	2Cs	0	0	8	NE18				
	1158	865	82.1	75.0	72	8	2CuE25	6Cs	0	0	3	ENE17				
	1256	850	80.4	73.6	73	9	2CuE25	6Cs	0	0	9	ENE14				
	1358	825	84.1	75.4	67	4	2CuE25	2Cs	0	0	4	NE16				
	1459	800	85.0	75.6	65	4	2CuE25	2Cs	0	0	4	NE16				
	1557	790	85.1	75.8	65	3	2CuE25	1Cs	0	0	3	NE16				
	1658	785	83.0	75.3	70	8	4CuE25	6AcE70e	0	0	8	ENE16				
	1755	800	83.0	75.0	69	8	3CuE15	4ScE25e	2AcE70	0	8	ENE16				
	1858	810	81.0	74.5	74	3	3CuE22	0	0	0	3	ENE18				
	1958	825	80.2	74.2	76	2	2CuE22	0	0	0	2	ENE20				
	2056	835	80.0	74.0	75	3	2CuE22	1AsE100	0	0	3	ENE19				
	2156	845	79.6	75.0	81	3	2CuE22	1AcE100	0	0	3	ENE18				
	2258	840	79.4	74.0	78	3	3CuE22	0	0	0	3	E18				
	2355	850	79.4	74.0	78	3	3CuE22	0	0	0	3	E16		85	79	T
2/4	0059	855	79.4	74.0	78	3	3CuE25	0	0	0	3	E18				
	0159	855	79.3	73.9	78	2	2CuE25	0	0	0	2	E16				
	0256	845	79.2	73.9	78	5	5CuE25	0	0	0	5	E16				
	0355	840	79.0	73.7	78	10	5CuE25	10Cs	0	0	8	ENE14				
	0459	840	78.8	73.7	79	10	3CuE25	10AsE80e	Unknown	Unknown	10	ENE13				
	0556	830	78.8	73.7	79	10	10ScE25e	Unknown	Unknown	Unknown	10	E10	0542-0642			
	0657	840	76.5	72.4	82	9	9AsE80e	0	0	0	9	ENE8				
	0758	850	76.1	72.1	82	10	5CuE25	5AsE80e	Unknown	Unknown	10	ENE21				

PLACE: FRED HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19 (Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
2/4	0859	860	76.0	74.0	91	10	8CuE25e	2AsE80	Unknown	Unknown	10	ENE15	0814-0901			
	0957	880	79.4	75.0	82	5	3CuE25	2AsE100	0	0	5	E16				
	1058	885	79.4	75.0	82	10	3CuE25	7AsE80e	Unknown	Unknown	10	ENE14				
	1159	875	78.5	75.5	87	9	5CuE25	4AsE80e	0	0	9	ENE16				
	1258	850	81.9	76.9	80	8	6CuE25e	2AsE80	0	0	8	ENE16	1235-1241			
	1356	815	84.1	77.1	73	8	6CuE25e	2AsE80	0	0	8	ENE18				
	1459	805	83.0	76.0	73	4	2CuE25	2AsE80	0	0	4	ENE14				
	1557	775	83.4	75.4	69	4	2CuE25	2AsE80	0	0	4	ENE15				
	1656	770	81.1	75.0	75	10	10ScE15e	Unknown	Unknown	Unknown	10	ENE20	1609-1614			
	1759	775	80.6	76.1	81	9	2CuE25	7AcE80e	0	0	9	NE18	1642-1645			
	1857	775	80.3	76.1	82	4	4CuE25	0	0	0	4	NE18	1655-1709			
	1958	790	80.0	75.2	80	4	4CuE25	0	0	0	4	ENE18				
	2059	800	80.1	75.1	79	2	2CuE25	0	0	0	2	NE18				
	2156	810	79.9	74.8	79	2	2CuE25	0	0	0	2	ENE17				
	2257	815	79.8	75.1	81	5	5CuE25	0	0	0	5	ENE16				
	2358	835	79.7	75.8	83	7	7CuE25e	0	0	0	7	NE16		84	76	0.03
2/5	0057	835	79.8	75.2	81	6	2CuE25	6AcE100e	0	0	6	ENE16				
	0158	830	80.0	75.0	79	8	2CuE22	8AcE100e	0	0	8	ENE18				
	0256	820	79.8	74.8	79	10	2CuE21	10AcE100e	Unknown	Unknown	10	ENE16				
	0358	810	78.6	75.0	85	3	3CuE22	0	0	0	3	E13	0321-0326			
	0459	805	79.5	74.9	81	3	3CuE22	0	0	0	3	ENE20				
	0555	780	79.8	75.2	81	3	3CuE22	0	0	0	3	ENE20				
	0658	780	79.5	75.2	82	2	2CuE22	0	0	0	2	E18				
	0757	780	79.9	75.0	80	3	3CuE22	0	0	0	3	E16				
	0859	790	80.3	75.0	78	3	3CuE22	0	0	0	3	E16				
	0957	815	82.1	75.0	72	3	3CuE22	0	0	0	3	E16				
	1058	820	82.1	75.0	72	3	3CuE22	0	0	0	3	E17				
	1159	830	83.2	75.2	69	1	1CuE22	0	0	0	1	E14				
	1257	815	84.0	74.0	63	1	1CuE22	0	0	0	1	E14				
	1358	790	84.0	76.0	69	1	1CuE22	0	0	0	1	E20				
	1459	790	84.2	75.2	66	1	1CuE22	0	0	0	1	E14				
	1558	790	84.2	74.0	62	1	1CuE22	0	0	0	1	E19				
	1657	790	84.1	74.6	64	1	1CuE22	0	0	0	1	ENE16				
	1758	775	82.3	74.7	70	1	1CuE25	0	0	0	1	ENE16				
	1856	790	80.4	73.6	72	2	2CuE25	0	0	0	2	ENE16				
	1957	800	79.9	72.6	71	1	1CuE25	0	0	0	1	ENE17				
	2057	810	80.0	72.9	71	1	1CuE25	0	0	0	1	ENE15				
	2158	820	79.8	72.1	69	1	1CuE25	0	0	0	1	ENE15				
	2256	825	79.5	71.9	69	5	5CuE25	0	0	0	5	ENE14				
	2357	825	79.1	70.3	65	2	2CuE25	0	0	0	2	ENE16		84	79	T

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HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19
(Continued)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
2/6	0056	830	78.9	70.1	65	2	2CuE22	0	0	0	2	ENE15				
	0159	830	78.6	70.1	66	2	2CuE22	0	0	0	2	ENE14				
	0256	825	78.2	70.3	68	0	0	0	0	0	0	NE12				
	0358	820	78.8	71.6	70	7	2CuE22	7AcE100e	0	0	7	NE12				
	0459	820	77.0	72.0	79	10	3CuE22	10ScE55a	Unknown	Unknown	10	NE15				
	0555	815	77.8	72.4	77	8	3CuE22	8ScE50e	0	0	8	NE15				
	0659	820	77.9	73.0	79	10	2CuE22	4ScE50e	4AcE80	Unknown	10	NE14				
	0759	830	79.8	72.4	70	10	2CuE22	6ScE50e	2Ac 80	0	9	ENE12				
	0856	850	80.0	72.4	70	10	6ScE50e	4AcE80	Unknown	Unknown	10	NE15				
	0956	865	81.3	73.1	68	10	10ScE50e	Unknown	Unknown	Unknown	10	ENE16				
	1057	880	83.8	72.4	58	3	1CuE25	2Ac 80	0	0	3	NE12				
	1156	850	84.9	72.8	56	9	2CuE25	7AcE120e	0	0	9	NE16				
	1258	830	83.3	73.5	63	10	6CuE25e	4AcE120	0	0	9	ENE16				
	1358	800	84.9	73.7	59	3	1CuE25	2AcE120	0	0	3	ENE16	1309-1313			
	1456	770	85.0	73.0	57	1	1CuE25	0	0	0	1	NE16				
	1559	760	84.2	72.5	57	1	1CuE25	0	0	0	1	NE16				
	1658	760	83.2	72.2	59	1	1CuE25	0	0	0	1	E12				
	1759	785	83.2	71.0	55	1	1CuE25	0	0	0	1	ENE16				
	1859	785	81.2	70.2	58	1	1AcE80	0Ci	0	0	1	ENE12				
	1958	795	80.0	71.0	64	1	1AcE100	0	0	0	1	ENE14				
	2059	795	79.8	71.8	68	0	0	0	0	0	0	ENE13				
	2158	795	79.0	71.7	73	0	0	0	0	0	0	ENE13				
	2257	800	79.0	71.7	73	2	1CuE25	1Ci	0	0	2	ENE14				
	2359	795	79.0	71.7	73	4	4CuE25	0	0	0	4	ENE14		85	77	T
2/7	0057	795	79.1	71.8	70	5	5CuE25	0	0	0	5	NE14				
	0156	790	78.7	71.0	69	5	5CuE25	0	0	0	5	NE15				
	0258	780	78.4	71.3	71	5	5CuE25	0	0	0	5	NE14				
	0359	775	78.5	71.4	71	3	3CuE25	0	0	0	3	ENE12				
	0456	775	78.2	71.8	73	5	5CuE25	0	0	0	5	NE16				
	0558	780	78.3	71.6	72	3	3CuE25	0	0	0	3	NE15				
	0659	790	78.5	71.6	72	5	3CuE25	2AcE80	0	0	5	ENE20	0620-0628			
	0757	800	79.0	71.0	68	2	2CuE20	0	0	0	2	ENE16				
	0856	810	81.5	72.0	63	2	1CuE20	1Ci	0	0	2	ENE16				
	0956	825	81.8	71.8	62	3	2CuE20	1AcE80	0	0	3	ENE18				
	1056	830	82.8	72.8	62	3	2CuE20	1AcE80	0	0	3	ENE12				
	1156	820	82.8	72.8	62	4	4CuE20	0	0	0	4	ENE16				
	1259	810	84.9	73.8	59	4	4CuE20	0	0	0	4	ENE16				
	1358	790	85.0	74.7	62	3	3CuE20	0	0	0	3	ENE16				
	1456	775	84.8	73.6	59	4	4CuE20	0	0	0	4	ENE14				
	1556	755	85.0	74.0	59	3	3CuE20	0	0	0	3	ENE16				
	1657	760	83.6	73.6	62	3	2CuE20	1AcE120	0	0	3	ENE14				
	1759	775	82.2	74.2	65	3	2CuE20	1AcE120	0	0	3	ENE16				

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HOURLY OBSERVATIONS AND DAILY SUMMARY JANUARY 25 - FEBRUARY 8, 1958

TABLE 19 (Concluded)

DATE	TIME	P	TT	TT_w	RH	N	CLOUDS AND OBSCURING PHENOMENA (Amount-type-direction-height) 1st Layer	2nd Layer	3rd Layer	4th Layer	N_O	DDFF	TIMES OF RAINFALL	DAILY SUMMARY T_xT_x	T_nT_n	RR
2/7	1858	780	79.4	74.0	78	2	2CuE25	0	0	0	2	E12				
	1957	780	79.6	73.0	73	3	1CuE25	2Ci	0	0	1	ENE14				
	2059	785	79.4	74.0	78	0	0	0	0	0	0	ENE15				
	2158	790	79.2	72.8	74	0	0	0	0	0	0	ENE13				
	2257	795	79.2	72.8	74	3	3Ci	0	0	0	0	E12				
	2359	795	79.2	72.8	74	2	2CuE25	0	0	0	2	E10		85	78	T
2/8	0058	800	78.8	71.9	72	3	3CuE25	0	0	0	3	ENE14				
	0156	790	78.6	72.0	73	5	5CuE25	0	0	0	5	ENE14				
	0257	780	78.8	72.1	73	5	5CuE25	0	0	0	5	E14				
	0356	770	78.2	71.6	73	5	5CuE25	0	0	0	5	ENE12				
	0458	770	78.4	71.9	73	3	3CuE25	0	0	0	3	ENE13				
	0559	770	78.3	71.2	71	3	3CuE25	0	0	0	3	ENE14				
	0659	775	78.0	71.6	74	5	2CuE25	3CsE	0	0	3	ENE15				
	0758	785	78.9	69.9	64	8	2CuE25	8CsE	0	0	2	ENE15				
	0856	800	80.2	71.8	67	10	2CuE25	10CsE	0	0	3	ENE15				
	0958	815	82.5	72.5	62	10	2CuE22	10CsE	0	0	3	ENE14				
	1057	820	83.2	73.0	62	10	2CuE22	10CsE	0	0	3	ENE16				
	1155	805	83.0	74.2	66	10	3CuE22	10CsE	0	0	4	E12				
	1256	785	84.5	74.9	64	10	1CuE22	10Cs	0	0	2	ENE14				
	1356	760	84.0	74.9	66	10	1CuE22	10Cs	0	0	2	E16				
	1456	740	84.0	74.2	63	7	1CuE22	7Cs	0	0	2	E15				
	1559	725	83.7	73.5	62	4	1CuE22	4Cs	0	0	1	E14				
	1658	725	83.2	74.0	65	4	1CuE22	4CiE	0	0	1	E14				
	1756	745	83.0	74.0	66	4	1CuE22	3Ci	0	0	3	E16				
	1857	750	81.3	72.3	67	2	2CuE22	0	0	0	2	ENE15				
	1959	750	80.2	71.5	64	1	1CuE22	0	0	0	1	ENE14				
	2056	760	80.0	71.5	65	0	0	0	0	0	0	E16				
	2159	765	79.3	73.4	76	0	0	0	0	0	0	ENE18				
	2259	770	79.0	73.5	77	0	0	0	0	0	0	E16				
	2356	770	79.0	73.5	77	0	0	0	0	0	0	E18		85	78	0

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
1/25	0200	1015	Surface	27.0	22.6	77	50 - 7
		1000	137	25.6	22.0	80	60 - 9
		850	1549	19.0	11.1	60	90 - 11
		700	3194	10.8	MB	(13)	100 - 10
		600	4459	2.2	MB	(14)	100 - 10
		500	5913	-5.0	MB	(15)	110 - 9
		400	7633	-16.9	MB	(14)	100 - 8
		300	9732	-31.0	MB	(20)	90 - 7
		200	12465	-54.2	----	--	110 - 5
		150	14252	-67.8	----	--	110 - 9
		100	16614	-74.2	----	--	90 - 8
	1130	1016	Surface	27.9	22.9	74	60 - 9
		1000	146	26.7	22.6	78	70 - 10
		850	1561	17.8	14.3	80	150 - 6
		700	3207	12.0	MB	(12)	60 - 7
		600	4476	4.3	MB	(13)	80 - 8
		500	5935	-3.5	MB	(14)	90 - 12
		400	7659	-14.7	MB	(16)	110 - 10
		300	9767	-29.9	MB	(20)	100 - 9
		200	12525	-52.0	----	--	100 - 11
		150	14329	-65.6	----	--	110 - 9
		100	16710	-76.8	----	--	120 - 9
	2330	1015	Surface	26.9	22.1	75	60 - 8
		1000	137	25.9	21.3	76	60 - 8
		850	1550	16.5	13.1	80	60 - 6
		700	3189	12.0	MB	(12)	80 - 5
		600	4461	4.1	MB	(13)	90 - 8
		500	5918	-4.9	MB	(15)	90 - 13
		400	7644	-15.6	MB	(17)	80 - 14
		300	9739	-32.3	MB	(20)	120 - 5
		200	12473	-53.2	----	--	90 - 13
		150	14261	-66.9	----	--	120 - 9
		100	16636	-75.9	----	--	110 - 5
1/26	1200	1016	Surface	25.4	19.1	67	40 - 9
		1000	145	24.6	18.5	69	40 - 8
		850	1546	14.2	8.7	70	40 - 9
		700	3183	11.0	MB	(13)	60 - 4
		600	4456	4.1	MB	(13)	50 - 4
		500	5912	-5.6	MB	(15)	110 - 8
		400	7638	-15.0	MB	(16)	160 - 11
		300	9744	-32.0	MB	(20)	90 - 9
		200	12470	-53.9	----	--	120 - 12
		150	14258	-67.4	----	--	110 - 7
		100	16622	-77.5	----	--	80 - 5
	2335	1013	Surface	27.3	22.3	74	50 - 8
		1000	119	26.1	21.6	76	50 - 9
		850	1528	16.8	10.9	68	76 - 11
		700	3171	10.8	MB	(13)	60 - 5
		600	4445	5.1	MB	(13)	50 - 13
		500	5911	-3.1	MB	(14)	120 - 12
		400	7646	-14.6	MB	(16)	70 - 10
		300	9750	-31.5	MB	(20)	110 - 8
		200	12493	-53.5	----	--	140 - 7
		150	14281	-67.6	----	--	130 - 9
		100	16636	-81.1	----	--	120 - 8

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
1/27	1210	1012	Surface	27.0	21.1	70	50 - 9
		1000	111	26.0	20.9	73	50 - 9
		850	1522	15.1	11.9	81	60 - 11
		700	3161	12.0	MB	(12)	80 - 10
		600	4441	6.7	MB	(13)	100 - 11
		500	5918	-1.5	MB	(14)	90 - 6
		400	7654	-14.5	MB	(16)	50 - 5
		300	9763	-30.5	MB	(20)	90 - 9
		200	12510	-52.3	----	--	160 - 9
		150	14306	-67.1	----	--	210 - 7
		100	16666	-79.1	----	--	190 - 7
	2340	1012	Surface	26.8	20.5	68	60 - 8
		1000	111	25.8	20.0	70	70 - 11
		850	1515	16.4	-0.7	31	100 - 10
		700	3155	10.7	MB	(13)	60 - 13
		600	4424	4.5	MB	(13)	80 - 8
		500	5890	-2.6	MB	(14)	70 - 11
		400	7617	-15.4	MB	(16)	40 - 13
		300	9720	-31.1	MB	(20)	60 - 8
		200	12470	-52.8	----	--	160 - 4
		150	14262	-66.1	----	--	170 - 9
		100	16632	-77.4	----	--	70 - 7
1/28	1137	1013	Surface	26.7	18.9	62	80 - 7
		1000	119	25.9	18.6	64	80 - 7
		850	1526	14.4	9.5	72	60 - 6
		700	3163	13.4	MB	(12)	60 - 9
		600	4444	7.2	MB	(13)	90 - 6
		500	5919	-2.0	MB	(14)	90 - 6
		400	7649	-15.0	MB	(16)	90 - 5
		300	9756	-31.0	MB	(20)	70 - 7
		200	12508	-52.3	----	--	270 - 7
		150	14307	-66.5	----	--	270 - 5
		100	16683	-76.6	----	--	90 - 3
	2332	1011	Surface	25.7	19.4	68	70 - 8
		1000	101	24.9	19.4	71	60 - 9
		850	1506	14.4	12.3	87	90 - 12
		700	3139	11.4	MB	(13)	110 - 4
		600	4414	6.7	MB	(13)	60 - 11
		500	5881	-3.9	MB	(14)	60 - 8
		400	7663	-16.0	MB	(17)	100 - 11
		300	9705	-31.3	MB	(20)	80 - 6
		200	12445	-53.1	----	--	310 - 6
		150	14238	-66.4	----	--	350 - 6
		100	16607	-73.2	----	--	140 - 9
1/29	1135	1012	Surface	26.7	20.6	69	90 - 10
		1000	111	25.7	20.1	71	90 - 10
		850	1515	15.4	8.0	61	90 - 8
		700	3149	10.7	MB	(13)	70 - 3
		600	4423	5.9	MB	(13)	30 - 9
		500	5895	-4.2	MB	(14)	20 - 11
		400	7625	-13.9	MB	(16)	60 - 9
		300	9728	-32.5	MB	(20)	50 - 5
		200	12448	-55.0	----	--	40 - 3
		150	14228	-67.6	----	--	20 - 9
		100	16596	-76.0	----	--	260 - 5

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
1/29	2359	1011	Surface	26.4	23.5	84	60 - 8
		1000	102	25.9	23.2	85	60 - 8
		850	1513	16.9	6.4	50	70 - 4
		700	3152	13.9	MB	(12)	140 - 3
		600	4433	6.0	MB	(13)	20 - 7
		500	5900	-3.5	MB	(14)	90 - 3
		400	7631	-13.6	MB	(16)	60 - 2
		300	9742	-31.3	MB	(20)	350 - 7
		200	12474	-52.6	----	--	240 - 7
		150	14268	-66.2	----	--	260 - 13
		100	16638	-79.9	----	--	350 - 11
1/30	1350	1011	Surface	25.3	21.7	80	100 - 5
		1000	101	24.8	21.2	80	100 - 5
		850	1514	17.9	4.2	40	130 - 2
		700	3147	12.7	-9.0	21	30 - 2
		600	4422	4.9	MB	(13)	30 - 3
		500	5895	-2.1	MB	(14)	20 - 6
		400	7627	-14.7	MB	(16)	80 - 6
		300	9724	-32.9	MB	(20)	310 - 3
		200	12456	-58.0	----	--	280 - 11
		150	14250	-66.3	----	--	360 - 4
		100	16623	-77.0	----	--	350 - 3
	2342	1010	Surface	26.9	23.0	79	70 - 7
		1000	94	26.2	22.5	80	70 - 7
		850	1507	18.4	13.1	71	110 - 3
		700	3141	6.4	5.2	92	60 - 2
		600	4413	4.4	MB	(13)	60 - 3
		500	5877	-3.9	MB	(14)	40 - 6
		400	7601	-15.5	MB	(17)	10 - 5
		300	9700	-32.5	MB	(20)	320 - 5
		200	12435	-53.0	----	--	260 - 13
		150	14227	-69.3	----	--	230 - 10
		100	16593	-78.9	----	--	280 - 3
1/31	1140	1011	Surface	24.3	18.5	70	80 - 7
		1000	101	23.3	18.7	75	80 - 7
		850	1495	14.1	8.8	70	90 - 6
		700	3112	11.0	MB	(13)	50 - 6
		600	4378	3.4	MB	(13)	110 - 3
		500	5831	-6.3	MB	(15)	40 - 7
		400	7536	-17.7	MB	(17)	360 - 7
		300	9615	-34.0	MB	(21)	330 - 6
		200	12323	-54.9	----	--	260 - 7
		150	14106	-67.5	----	--	240 - 13
		100	16468	-79.3	----	--	230 - 6
2/1	0100	1011	Surface	27.2	22.9	77	90 - 8
		1000	102	26.5	22.4	78	80 - 9
		850	1515	16.2	13.5	84	80 - 11
		700	3158	13.0	MB	(12)	60 - 4
		600	4438	7.0	MB	(13)	40 - 4
		500	5910	-3.4	MB	(14)	30 - 8
		400	7630	-16.9	MB	(17)	20 - 8
		300	9717	-32.5	MB	(20)	310 - 4
		200	12442	-53.5	----	--	290 - 8
		150	14229	-67.3	----	--	280 - 10
		100	16593	-78.4	----	--	270 - 12

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
2/1	1200	1012	Surface	27.0	20.1	66	90 - 9
		1000	111	26.2	20.4	70	90 - 9
		850	1518	15.2	8.7	65	80 - 10
		700	3155	12.6	MB	(12)	80 - 5
		600	4431	6.0	MB	(13)	50 - 10
		500	5894	-4.2	MB	(14)	70 - 6
		400	7616	-15.6	MB	(17)	20 - 11
		300	9719	-31.2	MB	(20)	310 - 5
		200	12446	-53.9	----	--	360 - 5
		150	14230	-66.8	----	--	230 - 14
		100	16600	-77.9	----	--	60 - 3
	2337	1012	Surface	25.9	23.0	84	60 - 9
		1000	111	25.0	22.6	86	70 - 9
		850	1520	16.3	16.2	99	80 - 11
		700	3142	7.0	MB	(13)	90 - 11
		600	4409	4.7	MB	(13)	90 - 14
		500	5870	-2.7	MB	(14)	50 - 11
		400	7596	-15.3	MB	(16)	20 - 16
		300	9691	-32.5	MB	(20)	310 - 10
		200	12411	-53.7	----	--	290 - 18
		150	14201	-66.0	----	--	300 - 15
		100	16574	-79.6	----	--	240 - 12
2/2	1200	1013	Surface	26.1	20.9	73	50 - 10
		1000	118	25.3	20.6	75	50 - 11
		850	1527	16.8	14.8	88	80 - 14
		700	3167	12.5	3.5	54	100 - 11
		600	4445	5.2	MB	(13)	80 - 12
		500	5902	-4.8	MB	(15)	40 - 15
		400	7618	-15.7	MB	(17)	20 - 13
		300	9713	-32.7	MB	(20)	10 - 15
		200	12440	-52.0	----	--	290 - 26
		150	14243	-65.4	----	--	320 - 15
		100	16624	-78.9	----	--	360 - 6
	2340	1011	Surface	26.5	20.4	69	50 - 12
		1000	102	25.5	19.9	71	60 - 12
		850	1509	17.0	11.9	72	70 - 11
		700	3149	12.0	MB	(12)	70 - 10
		600	4426	5.0	MB	(13)	80 - 12
		500	5886	-4.8	MB	(15)	60 - 10
		400	7601	-17.7	MB	(17)	10 - 12
		300	9678	-34.2	MB	(21)	340 - 13
		200	12387	-54.2	----	--	300 - 17
		150	14176	-65.8	----	--	310 - 14
		100	16549	-78.5	----	--	360 - 5
2/3	1200	1011	Surface	27.2	22.0	73	60 - 8
		1000	102	26.2	21.4	75	60 - 8
		850	1507	15.2	10.8	75	70 - 12
		700	3145	12.0	MB	(12)	70 - 14
		600	4419	5.6	MB	(13)	60 - 12
		500	5880	-5.7	MB	(15)	40 - 11
		400	7585	-19.6	MB	(17)	360 - 11
		300	9652	-32.0	MB	(20)	360 - 12
		200	12404	-52.1	----	--	360 - 15
		150	14208	-65.9	----	--	320 - 17
		100	16691	-77.7	----	--	270 - 15

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
2/3	2335	1011	Surface	26.3	21.6	75	70 - 9
		1000	102	25.6	21.3	77	70 - 9
		850	1507	16.9	-0.3	31	100 - 13
		700	3149	13.2	MB	(12)	70 - 13
		600	4424	3.9	MB	(13)	60 - 14
		500	5880	-6.0	MB	(15)	60 - 11
		400	7585	-18.9	MB	(17)	40 - 19
		300	9679	-30.1	MB	(20)	50 - 30
		200	12427	-53.9	----	--	40 - 28
		150	14214	-67.3	----	--	350 - 16
		100	16572	-77.5	----	--	340 - 14
2/4	1144	1012	Surface	26.2	21.0	73	80 - 8
		1000	111	25.4	20.9	76	70 - 13
		850	1519	16.0	14.5	91	90 - 8
		700	3155	8.8	7.2	89	100 - 11
		600	4423	3.0	MB	(13)	100 - 12
		500	5875	-5.2	MB	(15)	70 - 13
		400	7585	-19.0	MB	(17)	60 - 17
		300	9690	-29.9	MB	(20)	40 - 16
		200	12442	-52.0	----	--	10 - 11
		150	14242	-65.6	----	--	10 - 14
		100	16616	-75.6	----	--	40 - 9
	2337	1009	Surface	26.3	22.2	78	40 - 9
		1000	84	25.9	22.0	79	50 - 9
		850	1496	15.9	13.9	88	70 - 11
		700	3135	12.4	MB	(12)	80 - 11
		600	4407	3.0	MB	(13)	130 - 5
		500	5864	-4.6	MB	(15)	110 - 15
		400	7574	-18.0	MB	(17)	90 - 13
		300	9682	-30.5	MB	(20)	50 - 15
		200	12428	-53.5	----	--	340 - 7
		150	14219	-66.9	----	--	20 - 9
		100	16577	-79.9	----	--	60 - 10
2/5	1140	1009	Surface	25.0	19.0	69	70 - 8
		1000	84	24.5	18.9	71	60 - 8
		850	1492	16.9	10.9	68	50 - 8
		700	3139	12.8	MB	(12)	100 - 8
		600	4409	2.5	MB	(13)	60 - 7
		500	5869	-3.2	MB	(14)	50 - 9
		400	7600	-11.9	MB	(16)	40 - 9
		300	9725	-29.4	MB	(19)	70 - 5
		200	12477	-52.1	----	--	30 - 9
		150	14280	-65.2	----	--	50 - 4
		100	16661	-79.5	----	--	120 - 6
2/6	0200	1010	Surface	25.6	18.4	64	50 - 8
		1000	93	25.0	18.8	68	60 - 8
		850	1497	14.9	12.6	83	110 - 8
		700	3141	10.3	MB	(13)	50 - 6
		600	4406	3.9	MB	(13)	50 - 6
		500	5866	-5.0	MB	(15)	70 - 2
		400	7587	-15.9	MB	(17)	60 - 6
		300	9692	-31.1	MB	(20)	150 - 2
		200	12445	-52.7	----	--	150 - 4
		150	14238	-66.5	----	--	270 - 1
		100	16605	-80.0	----	--	350 - 5

DATE	TIME	LEVEL (mb.)	HEIGHT (m.)	TT (°C)	T_dT_d (°C)	RH	DDFF (m/s)
2/6	1138	1012	Surface	27.4	19.2	61	60 - 8
		1000	111	26.4	19.3	65	60 - 7
		850	1517	14.1	10.7	80	80 - 7
		700	3154	11.8	MB	(12)	80 - 5
		600	4427	4.9	MB	(13)	80 - 4
		500	5890	-5.0	MB	(15)	50 - 7
		400	7608	-17.3	MB	(17)	80 - 5
		300	9710	-30.0	MB	(20)	260 - 2
		200	12463	-52.5	----	--	260 - 5
		150	14259	-67.1	----	--	240 - 5
		100	16628	-80.1	----	--	330 - 3
	2343	1009	Surface	25.9	19.8	69	60 - 7
		1000	84	25.2	19.4	70	60 - 8
		850	1487	17.0	3.0	39	80 - 9
		700	3125	10.4	MB	(13)	60 - 8
		600	4394	5.2	MB	(13)	60 - 8
		500	5851	-5.7	MB	(15)	80 - 4
		400	7570	-15.2	MB	(16)	180 - 1
		300	9670	-32.3	MB	(20)	270 - 5
		200	12400	-54.6	----	--	250 - 8
		150	14181	-68.7	----	--	310 - 5
		100	16530	-79.7	----	--	330 - 4
2/7	1131	1010	Surface	26.5	20.1	68	60 - 8
		1000	94	25.7	19.7	69	60 - 8
		850	1501	15.2	7.5	60	70 - 11
		700	3135	11.3	MB	(13)	60 - 11
		600	4407	5.7	MB	(13)	30 - 4
		500	5870	-4.4	MB	(14)	40 - 4
		400	7595	-14.4	MB	(16)	100 - 2
		300	9702	-31.7	MB	(20)	280 - 8
		200	12444	-52.9	----	--	270 - 9
		150	14242	-66.8	----	--	330 - 7
		100	16612	-79.3	----	--	340 - 4
	2345	1009	Surface	25.8	20.5	72	70 - 7
		1000	84	25.1	20.2	74	70 - 7
		850	1490	15.6	8.4	62	70 - 11
		700	3130	10.5	MB	(13)	40 - 12
		600	4393	3.1	MB	(13)	30 - 6
		500	5849	-5.0	MB	(15)	360 - 2
		400	7569	-14.9	MB	(16)	310 - 3
		300	9671	-31.0	MB	(20)	290 - 13
		200	12414	-53.5	----	--	310 - 12
		150	14204	-67.8	----	--	300 - 10
		100	16565	-80.0	----	--	300 - 6
2/8	1132	1010	Surface	26.0	18.8	64	60 - 8
		1000	93	25.2	18.7	67	60 - 8
		850	1496	15.0	11.0	77	90 - 8
		700	3132	11.7	MB	(12)	60 - 8
		600	4404	4.0	MB	(13)	40 - 6
		500	5863	-4.5	MB	(15)	350 - 1
		400	7586	-15.5	MB	(17)	300 - 3
		300	9704	-29.8	MB	(20)	360 - 5
		200	12463	-53.5	----	--	270 - 12
		150	14258	-67.1	----	--	290 - 10
		100	16621	-88.2	----	--	320 - 6

PLACE: BRUCE THREE-HOURLY OBSERVATIONS, JANUARY 25 - FEBRUARY 8, 1958 TABLE 21

Date and Time		TT	TT_w	T_xT_x	T_nT_n	RR_L	RR_O	N	C_{LMH}	FF_3	DDFF	REMARKS
1/25	1200	84.5	77.5	----	----	0	0	1	1Cu.........	--	NE 10-12	
	1500	85.0	78.0	----	----	0	0	3	3Cu.........	12	NE 8-10	
	1800	82.0	77.0	----	----	0	0	2	1Cu;1Ci....	13	NE 8-10	
	2100	80.0	76.0	----	----	0	0	7	3Cu;5Ac;1Ci	12	NE 2-4	2100 rain in sight, E to S.
1/26	0000	79.0	74.0	86.0	79.0	0	0	0	(Cu).......	14	NE 12-15	
	0300	79.5	74.5	----	----	0	0	0	(Cu).......	13	NE 9-12	
	0600	79.0	73.5	----	----	0	0	0	(Cu).......	15	NE 12-15	
	0900	80.5	74.5	----	----	0	0	6	6Cu;2Ci....	16	NE 6-8	
	1200	83.5	74.0	83.5	78.5	0	0	4	4Cu;1Ci....	13	NE 8-10	
	1500	82.0	76.0	----	----	0	0	7	6Cu;2Ac;1Ci	13	NE 9-12	Between 1500 and 1800 7/10 Ci.
	1800	82.0	75.5	----	----	0	0	4	3Cu;1Ci....	10	NE 6-8	Between 1800 and 2100 5/10 Ac.
	2100	79.0	74.5	----	----	0	0	4	4Cu.........	12	E 10-12	
1/27	0000	79.0	73.0	85.5	79.0	0	0	2	2Cu.........	18	E 12-16	
	0300	78.5	72.5	----	----	0	0	2	2Cu.........	16	E 12-16	
	0600	78.5	73.0	----	----	0	0	1	1Cu.........	19	E 17-20	
	0900	80.5	73.0	----	----	0	0	0	(Cu).......	18	E 17-20	0900 heavy swelling Cu NW.
	1200	84.0	76.0	84.0	78.0	0	0	4	1Cu;3Ac....	17	NE 10-15	
	1500	84.0	76.0	----	----	0	0	3	2Cu;1Ci....	13	NE 10-15	
	1735	81.5	73.5	----	----	0	0	6	1Cu;5Ci....	13	NE 10-15	
	2035	79.0	73.5	----	----	0	0	-	....	13	NE 10-15	
	2335	79.0	72.5	----	----	0	0	4	3Cu;1Ci....	14	NE 12-15	
1/28	0235	78.0	73.5	----	----	0	0	-	....	14	NE 10-12	
	0535	78.0	73.5	----	----	0	0	-	....	13	NE 8-12	
	0900	80.0	71.5	----	----	0	0	3	2Cu;1Ci....	14	NE 8-12	
	1200	87.0	75.0	87.0	78.0	0	0	4	3Cu;1Ci....	12	NE 10-15	
	1500	87.0	75.0	----	----	0	0	2	2Cu.........	12	NE 8-12	
	1800	82.0	73.5	----	----	0	0	under 1	Ci.........	12	NE 8-12	
	2100	79.0	72.0	----	----	0	0	0	....	12	NE 8-12	
1/29	0000	78.0	72.5	87.5	78.0	0	0	-	....	13	NE 8-12	
	0300	78.0	73.5	----	----	0	0	-	....	10	NE 8-12	
	0600	78.0	73.5	----	----	0	0	-	....	12	NE 8-12	
	0900	80.5	75.0	----	----	0	0	5	5Cu.........	11	NE 8-12	
	1200	86.0	79.0	86.0	77.0	0	0	1	1Cu.........	10	NE 10	
	1500	86.5	78.5	----	----	0	0	2	2Cu.........	10	NE 10-15	
	1800	82.5	76.0	----	----	0	0	3	3Cu.........	10	NE 10	
	2100	80.0	75.0	----	----	0	0	3	3Cu.........	8	NE 10-12	
1/30	0000	78.5	75.0	87.5	78.5	0	0	3	3Cu.........	14	NE 15	
	0300	78.0	75.0	----	----	0	0	-	....	12	NE 10	0300 cloudy, rain.
	0600	75.5	71.0	----	----	0	0	-	....	7	NE 5-10	0600 cloudy, rain.
	0900	82.0	76.5	----	----	0	0	4	2Cu;2Ac....	3	NE 3-5	
	1200	86.0	79.0	86.0	75.5	0	0	7	5Cu;2Ci....	5	NE 5	
	1500	88.0	80.0	----	----	0	0	5	4Cu;1Ci....	6	NE 5	
	1800	84.0	77.5	----	----	0	0	4	4Cu.........	5	NE 5	
	2100	80.0	77.0	----	----	0	0	4	4Cu.........	8	NE 5-10	

PLACE: BRUCE

THREE-HOURLY OBSERVATIONS, JANUARY 25 - FEBRUARY 8, 1958

TABLE 21 (Continued)

Date	Time	TT	TT_w	T_xT_x	T_nT_n	RR_L	RR_O	N	C_{LMH}	FF_3	DDFF	REMARKS
1/31	0000	80.0	75.0	90.0	80.0	0	0	-	....	10	NE 10	0000 cloudy, Cu visible.
	0300	79.0	75.0	----	----	0	0	-	....	10	NE 10	0300 cloudy.
	0600	79.0	75.0	----	----	0	0	-	....	10	NE 10	0600 some clouds visible.
	0900	81.0	75.5	----	----	0	0	2	2Cu........	10	NE 15	
	1200	86.5	79.0	86.5	78.5	0	0	7	7Cu;1Ac....	10	NE 9**	1406-1416 rain.
	1500	85.0	79.0	----	----	0.05	0.03	5	5Cu;1Ac....	10	NE 9**	
	1800	82.5	76.0	----	----	0	0	3	3Cu........	11	NE 9**	
	2100	79.0	76.0	----	----	0	0	3	....	13	NE 11**	
2/1	0000	79.0	74.5	87.0	79.0	0	0	3	....	13	NE 11**	
	0300	79.0	75.0	----	----	0	0	3	....	14	NE 11**	
	0600	78.5	74.5	----	----	0	0	-	....	14	NE 12**	0800-0900 intermittent rain.
	0900	79.0	75.0	----	----	0.07	0.06	9	2Cu;7Sc....	13	NE 12**	0907 sun appeared. 0941-0945 and 0950-0953
	1200	84.0	75.0	84.0	76.0	0.01	0.02	1	1Cu........	13	NE 12**	rain.
	1500	85.0	77.5	----	----	0	0	1	1Cu........	12	NE 11**	
	1800	81.0	75.0	----	----	0	0	1	1Cu........	12	NE 11**	
	2100	79.0	73.5	----	----	0	0	1	....	12	NE 12**	
2/2	0000	78.0	75.0	86.0	76.5	T	T	2	....	14	NE 12**	0230-0245 heavy rain with high winds.
	0300	76.0	74.5	----	----	0.16	0.13	10	....	15	NE 17**	
	0600	79.0	75.0	----	----	0.01	0.02	7?	....	18	NE 18**	
	0900	80.0	75.0	----	----	0	0	8	6Sc;4Ac....	19	NE 18**	0916-0940 rain. 0940-1015 intermittent shwr.
	1200	81.0	77.0	81.0	76.0	0.10	0.10	10	9Cu;(Ci)...	18	NE 19*	1120-1125 rain. 1200 light shwr. 1240-1250
	1500	82.0	75.5	----	----	0.01	0.01	10	10Cu;1Ci...	18	NE 15*	light rain and gusty.
	1800	80.5	75.0	----	----	0	0	10	10Cu;1Ci...	20	NE 19*	
	2100	79.0	73.0	----	----	0	0	1	1Cu........	20	NE 17*	2100 moonlight.
2/3	0000	78.5	73.0	82.5	78.5	0	0	6	6Cu........	19	NE 19*	0000 moonlight.
	0300	78.5	74.0	----	----	0	T	8	8Cu........	19	NE 17*	0300 moonlight. 0555-0600 rain.
	0600	76.5	73.0	----	----	0.01	0.02	10?	....	16	NE 12*	0650-0700 rain.
	0900	78.5	73.0	----	----	0.02	0.01	3	3Cu........	14	NE 11*	0940-0950 rain.
	1200	80.0	75.0	80.0	75.5	0.01	0.02	8	8Cu........	14	NE 17*	1200 light shwr. 1205-1210 light shwr.
	1500	81.5	75.0	----	----	0	0	0	(Cu).......	15	NE 14*	
	1800	80.5	75.0	----	----	0	0	6	6Cu;(Ci)...	15	NE 14*	2045-2048 light shwr.
	2100	76.5	73.0	----	----	T	0	9	6Cu;3Ci....	14	NE 9*	2100 moonlight.
2/4	0000	78.0	73.5	82.0	76.0	0	0	2	2Cu........	13	NE 10*	0000 moonlight.
	0300	78.0	74.0	----	----	0	0	3	3Cu;1Ci....	11	NE 8*	0300 moonlight.
	0600	79.0	74.5	----	----	0	0	10	....	11	NE 10*	0600 cloudy, light shwr. 0620-0630 rain.
	0900	76.5	74.5	----	----	0.14	0.13	10	10Cu;3Ci...	11	NE 12*	0708-0715 rain. 0740-0845 intermittent shwrs.
	1200	80.0	77.0	80.0	76.5	T	T	6	5Sc;2Ac....	12	NE 10	0900 hazy sun. 1111-1117 rain.
	1500	80.0	76.0	----	----	T	T	7	6Sc;2Ac....	13	NE 14	
	1800	79.0	76.0	----	----	0	0	6	5Sc;2Ac....	13	NE 15	1800 shwrs over lagoon SW to W.
	2100	79.0	74.5	----	----	0	0	1	....	16	NE 12	Much of the day shwrs were apparently passing
2/5	0000	79.0	75.0	81.5	79.0	0	0	8	....	13	NE 10	N of Bruce as evidenced by clouds and short
	0300	79.0	75.0	----	----	0	0	9	....	14	NE 12	period when a few drops were felt.
	0600	79.0	74.5	----	----	0	0	5	....	15	NE 14	
	0900	80.0	74.0	----	----	0	0	4	2Cu;3Ac....	14	NE 14	
	1200	85.0	76.0	85.0	78.0	0	0	3	3Cu........	14	NE 12	

PLACE: BRUCE

THREE-HOURLY OBSERVATIONS, JANUARY 25 - FEBRUARY 8, 1958

TABLE 21
(Concluded)

Date	Time	TT	TT_w	T_xT_x	T_nT_n	RR_L	RR_O	N	C_{LMH}	FF_3	DDFF	REMARKS
2/5	1500	85.0	75.0	----	----	0	0	2	2Ac........	12	NE 12	
	1800	82.0	74.5	----	----	0	0	3	3Cu........	15	NE 12	
	2100	78.5	73.0	----	----	0	0	3	....	12	NE 9	
2/6	0000	78.0	72.0	85.5	78.0	0	0	3	....	13	NE 10	
	0300	77.5	72.5	----	----	0	0	3	....	11	NE 10	
	0600	78.0	72.5	----	----	0	0	10	....	12	NE 10	
	0900	79.0	72.0	----	----	T	T	10	10Cu.......	12	NE 8	
	1200	84.5	75.0	84.5	76.5	0	0	9	9Cu........	12	NE 10	
	1500	84.0	74.5	----	----	0	0	0	(Cu).......	15	NE 10*	
	1800	83.0	78.0	----	----	0	0	0	(Cu).......	12	NE 10	
	2100	79.0	73.5	----	----	0	0	1	....	12	NE 10*	
2/7	0000	77.5	72.5	84.5	77.5	0	0	10	2Cu;8Ci....	11	NE 12*	0000 moonlight.
	0300	78.0	72.0	----	----	0	0	2	2Cu........	14	NE 10*	0300 moonlight. 0430-0435 light rain.
	0600	78.0	72.5	----	----	0.01	0.01	4	4Cu........	13	NE 14*	0600 moonlight. 0630-0632 light rain.
	0900	78.5	71.5	----	----	0	T	1	1Cu........	11	NE 8*	
	1200	83.0	74.0	83.0	76.0	0	0	5	5Cu........	14	NE 10	1230 well developed Cb to NW.
	1500	85.0	75.0	----	----	0	0	5	5Cu........	11	NE 10	
	1800	81.5	75.0	----	----	0	0	2	2Cu........	12	NE 10	1800 shwr line E to SE. 1830-1835 light shwr.
	2100	78.5	73.0	----	----	T	T	2	2Cu........	12	NE 12	
2/8	0000	78.0	72.5	85.5	78.0	0	0	7	7Cu........	11	NE 9	
	0300	77.5	72.5	----	----	0	0	8	8Cu........	10	NE 10	
	0600	78.0	72.0	----	----	0	0	5	5Cu........	11	NE 10	
	0900	80.0	73.0	80.0	77.5	0	0	9	4Cu;5Ci....	12	NE 12	

PLACE: BRUCE

HOURLY RELATIVE HUMIDITIES, JANUARY 25 - FEBRUARY 8, 1958*

TABLE 22

HOUR:	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
DATE																								
1/25												71	--	--	74	--	--	80	--	--	84	--	--	79
1/26	--	--	79	--	--	77	--	--	76	--	--	64	--	--	76	--	--	74	--	--	81	--	--	75
1/27	--	--	75	--	--	77	--	--	72	--	--	69	--	--	69	--	--	--	--	--	--	--	--	--
1/28	--	--	--	--	--	--	--	--	67	--	--	57	--	--	57	--	--	73	--	--	71	--	--	77
1/29	--	--	82	--	--	82	--	--	78	--	--	75	--	--	68	--	--	74	--	--	79	--	--	82
1/30	--	--	84	--	--	82	--	--	78	--	--	74	--	--	71	--	--	75	--	--	87	--	--	79
1/31	--	--	83	--	--	83	--	--	78	71	72	72	66	98	77	72	74	74	82	84	87	85	82	81
2/1	85	84	83	84	83	83	80	81	83	83	80	66	65	66	72	73	74	76	77	77	77	81	84	87
2/2	88	95	93	93	90	83	82	81	80	81	82	84	--	--	74	--	--	78	--	--	76	--	--	77
2/3	--	--	81	--	--	85	--	--	77	--	--	80	--	--	74	--	--	78	--	--	85	--	--	81
2/4	--	--	83	--	--	81	--	--	91	--	--	87	90	88	83	84	86	87	82	84	81	84	85	83
2/5	82	82	83	86	84	81	80	79	76	70	66	67	62	64	63	66	69	70	76	77	77	77	76	75
2/6	76	77	79	81	76	77	77	75	71	72	62	64	54	62	64	65	70	80	82	81	77	82	83	79
2/7	81	81	75	80	82	77	79	74	71	70	68	66	65	64	63	69	72	74	76	76	77	77	77	77
2/8	77	78	79	77	76	75	74	74	72															

* Because of delay in receipt of hygrothermograph and malfunctioning for a brief period, the hourly record is incomplete as shown.

PLACE: BRUCE AND KEITH SPECIAL OBSERVATIONS, JANUARY 28, 1958 TABLE 23

BRUCE 0730-0815

LOCATION	WATER DEPTH	NO. OF MEASUREMENTS	TT_s* (°C)	TT_s (mean in °F.)
Lagoon, ½ ft. from shore	2 in.	5	4 - 26.2; 26.1	79.1
Lagoon, 5 ft. from shore	1 ft.	6	5 - 26.2; 26.3	79.2
Lagoon, 8 ft. from shore	2 ft.	5	3 - 26.2; 2 - 26.3	79.2
Lagoon, 5 yds. from shore	3 ft.	5	4 - 26.3; 26.2	79.3
Lagoon, 6 yds. from shore	4 ft.	5	5 - 26.3	79.3
Lagoon, 8 yds. from shore	5 ft.	5	3 - 26.4; 2 - 26.3	79.4
Ocean, ½ ft. from shore	2 in.	5	3 - 24.0; 23.9; 24.1	75.2
Ocean, 3-4 yds. from shore	6 in.	5	3 - 25.5; 25.6; 25.7	78.0
Ocean, 25 yds. from shore	1 in.	5	26.4; 3 - 26.5; 26.6	79.7
Ocean, 50 yds. from shore	2 in.	5	5 - 26.7	80.1
Ocean, 75-100 yds. from shore; 20 yds. from edge of reef	3 in.	5	5 - 26.7	80.1

BRUCE 1400-1515

LOCATION	WATER DEPTH	NO. OF MEASUREMENTS	TT_s* (°C)	TT_s (mean in °F.)
Lagoon, ½ ft. from shore	2 in.	5	2 - 27.4; 3 - 27.5	81.4
Lagoon, 5 ft. from shore	1 ft.	5	4 - 27.3; 27.4	81.2
Lagoon, 7 ft. from shore	2 ft.	5	5 - 27.3	81.1
Lagoon, 10 ft. from shore	3 ft.	5	4 - 27.2; 27.1	80.9
Lagoon, 3 yds. from shore	4 ft.	5	2 - 27.1; 3 - 27.2	80.9
Lagoon, 7-8 yds. from shore	5 ft.	5	2 - 27.0; 3 - 27.1	80.7
Ocean, in tidal pool at shore	1-2 in.	5	3 - 32.3; 32.4; 32.5	90.2
Ocean, in tidal pool at shore	3 in.	5	31.4; 2 - 31.5; 2 - 31.6	88.7
Ocean, 10 yds. from shore	6 in.	5	28.0; 2 - 28.1; 2 - 28.3	82.8
Ocean, 25 yds. from shore	6 in.	5	3 - 27.7; 2 - 27.8	81.9
Ocean, 50 yds. from shore	6 in.	5	3 - 27.5; 27.6; 27.7	81.6

BRUCE 1400-1515

LOCATION	WATER DEPTH	NO. OF MEASUREMENTS	TT_s* (°C)	TT_s (mean in °F.)
Ocean, about 100 yds. from shore; 10 yds. from edge of reef	1 ft.	5	27.0; 2 - 27.1; 2 - 27.2	80.8

KEITH 1520-1550

LOCATION	HEIGHT	TT	TT_w
Lagoon side, on open ridge at upper end of beach, about 20 yds. from water	5 ft.	83.0	74.0
Among coconut trees, 50 yds. NW of tent, 10 yds. from open lagoon beach	5 ft.	81.5	72.0
Among Pisonia, ocean side of path, 150 yds. WNW of tent, halfway between ocean beach and path	5 ft.	87.0	75.0
At upper edge of ocean beach, about 10 yds. from water	5 ft.	84.0	75.0

* Underlined values show number of observations at same temperature reading. Thus: 3 - 26.4 indicates 3 readings of 26.4°C.

KEITH, JANUARY 27

TIME	LOCATION	WATER DEPTH	NO. OF MEASUREMENTS	TT_s** (°C)
0730	Lagoon surface water	1-2 ft.	3	25.0
1420	Ocean side of reef, surface water	1 ft.	3	30.0

KEITH, JANUARY 28

TIME	LOCATION	WATER DEPTH	NO. OF MEASUREMENTS	TT_s** (°C)
1415	Lagoon, successive surface water readings out to 50 yards from shore	1-1½ ft.	6	28.5

** Readings constant within 0.5°C.

PLACE: KEITH

THREE-HOURLY OBSERVATIONS, JANUARY 25 - FEBRUARY 8, 1958

TABLE 24

Date	Time	TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	FF_3	DDFF	REMARKS
1/25	1200	--	--	----	----	--	2	2Cu........	--	E 8-10	
	1500	85.0	77.5	----	----	0	3	3Cu........	16	E 10-12	
	1800	82.0	76.5	----	----	0	4	4Cu;1Ci....	16	E 8-10	
	2100	80.0	76.0	----	----	0	6	3Cu;3Ac....	16	E 10-15	2100 moonlight.
1/26	0000	79.5	75.0	86.0	79.5	0	-	....	18	E 10-15	
	0300	79.0	74.0	----	----	0	-	....	14	E 10-15	
	0600	79.0	73.5	----	----	0	3	3Cu........	18	E 10-15	
	0900	80.0	73.0	----	----	0	8	4Cu;7Ci....	16	E 10-15	
	1200	83.5	75.0	83.5	78.5	0	4	4Cu;1Ci....	17	E 10-15	
	1500	83.0	74.5	----	----	0	8	4Cu;3Ac;4Ci	15	E 10-15	
	1800	80.5	74.0	----	----	0	4	3Cu;2Ci....	14	E 10-15	
	2100	80.0	73.5	----	----	0	4	4Cu........	14	E 10-12	2100 moonlight.
1/27	0000	79.0	73.5	84.0	79.0	0	-	....	18	E 10-15	
	0300	77.5	73.5	----	----	T	-	....	16	E 10-15	0255-0305 light shwr.
	0600	79.0	73.0	----	----	T	5	5Cu........	19	E 10-15	
	0900	80.0	73.5	----	----	0	3	2Cu;1Ci....	20	E 10-15	0900 towering Cu NE.
	1200	82.0	73.5	82.0	76.5	0	1	Cu,Sc,Ci..	25	NE 17*	
	1500	84.0	74.5	----	----	0	1	Cu,Ci......	18	NE 17*	
	1800	81.0	73.0	----	----	0	8	(Cu);8Cs...	17	NE 17*	
	2100	79.0	72.0	----	----	0	2	....	17	NE 12	
1/28	0000	79.0	72.0	84.0	79.0	0	2	2Cu........	18	NE 15	
	0300	78.0	73.0	----	----	0	2	2Cu........	17	NE 15	
	0600	78.0	72.0	----	----	0	2	....	17	NE 10-12	
	0900	80.0	72.0	----	----	0	4	(Cu);4Cs...	16	NE 16*	
	1200	84.0	75.0	84.0	78.0	0	1	1Cu,Ci......	15	NE 10*	
	1500	84.0	74.5	----	----	0	under 1	(Cu,Ci)....	17	NE 15*	
	1800	81.5	73.0	----	----	0	0	....	14	NE 12*	1800 two thin streaks Ci to N.
	2100	79.5	71.5	----	----	0	under 2	....	13	NE 8*	2100 sky at least .8 clear.
1/29	0000	79.0	73.5	85.5	79.0	0	2-4	Cu,Ci?....	14	NE 10	
	0300	78.5	73.5	----	----	0	-	....	15	NE 10	0300 some Cu.
	0600	78.0	74.0	----	----	0	-	....	13	NE 8-10	0600 some Cu.
	0900	80.0	74.5	----	----	0	3	3Cu........	13	NE 12*	
	1200	85.5	76.0	85.5	78.0	0	5	4Cu;2Ci....	11	E 8-10	
	1500	87.0	76.5	----	----	0	2	2Cu........	12	E 8-10	
	1800	83.0	76.0	----	----	0	4	4Cu;1Ci....	12	NE 6-8	
	2100	80.0	75.0	----	----	0	3	3Cu........	14	NE 10-12	2100 moonlight.
1/30	0000	80.0	75.0	87.0	80.0	0	6	6Cu........	16	NE 8-10	0000 moonlight.
	0300	77.5	74.5	----	----	0	-	....	11	NE 8-10	
	0600	78.0	75.0	----	----	0	-	....	14	NE 8-10	
	0900	80.0	73.5	----	----	0	7	2Cu;7Cs....	7	NE 8-10	
	1200	87.5	79.0	87.5	77.0	0	5	2Cu;4Ci....	7	NE 6-8	
	1500	88.5	78.0	----	----	0	4	1Cu;2Ac;2Ci	7	NE 6-8	
	1800	84.0	77.0	----	----	0	4	4Cu........	9	NE 8-10	

PLACE: KEITH

THREE-HOURLY OBSERVATIONS, JANUARY 25 - FEBRUARY 8, 1958

TABLE 24 (Continued)

Date	Time	TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	FF_3	DDFF	REMARKS
1/30	2100	81.0	76.5	----	----	0	5	3Cu;3Ci....	11	NE 10-12	2100 moonlight.
1/31	0000	80.5	76.5	89.0	80.5	0	-	....	13	E 10-15	0000 cloudy.
	0300	79.0	76.0	----	----	0	-	....	13	NE 8-10	0300 cloudy.
	0600	79.0	75.5	----	----	0	3	3Cu;1Ci....	11	NE 8-10	
	0900	81.0	76.5	----	----	0	3	3Cu........	12	E 8-10	
	1200	86.5	79.0	86.5	78.5	0	5	5Cu........	14	NE 11*	1200 Cu moving from NE. 1202-1204 shwrs. 1355-1356 shwrs. 1411-1414 shwrs. 1500 Cu moving from NE. Rain to NW. 1506-1509 shwrs. 1800 cloud moving from NE. 2100 cloud moving from NE.
	1500	87.5	80.5	----	----	T	8	8Cu........	12	NE 11*	
	1800	82.0	77.5	----	----	T	3	3Cu........	13	NE 10*	
	2100	79.5	75.5	----	----	0	3	3Cu........	15	NE 12*	
2/1	0000	79.0	74.5	87.5	79.0	0	3	3Cu........	17	NE 14	0205-0210 shwrs.
	0300	78.0	75.5	----	----	0.06	0	(Cu).......	15	E 14	0300 rain to N.
	0600	77.5	75.0	----	----	T	3	3Cu........	15	E 10*	0600 cloud moving from NE. 0830-0840 shwrs.
	0900	78.0	76.5	----	----	T	8	3Cu;6Ac....	18	NE 11*	0900 rain to W. 0938-0944 shwr. 1011-1014 shwr.
	1200	84.0	75.5	84.0	75.5	0.04	3	2Cu;1Ac....	16	N 11*	1121-1126 rain.
	1500	85.0	75.5	----	----	0	0	0..........	14	NE 12*	
	1800	81.0	76.0	----	----	0	0	(Cu).......	17	NE 13*	
	2100	79.0	76.0	----	----	0	2	2Cu........	15	NE 13	2300-0800 intermittent shwrs.
2/2	0000	77.0	76.0	86.5	77.0	T	10	6Cu;2Ci;4Ac	17	NE 14	
	0300	75.0	72.5	----	----	0.04	10	10Cu.......	18	E 16	
	0600	79.0	75.0	----	----	0.08	10	10Cu.......	22	E 18*	0600 raining.
	0900	79.5	75.0	----	----	T	6	3Cu;2Ci;3Ac	23	E 21*	1155-1206 rain.
	1200	78.0	75.0	80.0	75.0	0.02	9	4Cu;5Ci;4Ac	22	NE 24*	1200 raining. 1235-1245 rain. 1315-1320 rain.
	1500	82.0	75.5	----	----	0.01	10	4Cu;10Cs...	20	NE 21*	
	1800	81.0	75.5	----	----	0	9	3Cu;5Ci;6Ac	23	NE 22*	
	2100	79.5	74.0	----	----	0	3	3Cu........	25	NE 19*	2100 moonlight.
2/3	0000	79.0	73.0	82.5	76.0	0	2	2Cu........	24	NE 20*	0000 moonlight.
	0300	79.0	73.0	----	----	0	3	3Cu........	19	NE 20*	0300 moonlight.
	0600	78.5	73.0	----	----	0	4	4Cu........	22	NE 20*	0630-0635 rain. 0655-0700 rain. 0725-0735 rain.
	0900	79.5	74.0	----	----	T	5	3Cu;3Ac....	18	NE 19*	0900 towering Cu to N. 1025-1038 rain.
	1200	82.0	75.5	82.0	77.0	0.02	5	3Cu;3Ci....	19	NE 16*	
	1500	82.5	75.0	----	----	0	2	1Cu;2Ac....	16	NE 14*	
	1800	81.0	75.0	----	----	0	8	3Cu;8Ac....	16	NE 14*	
	2100	79.5	74.0	----	----	0	4	1Cu;4Ci....	19	NE 10-15	2100 moonlight.
2/4	0000	79.0	74.0	83.5	79.0	0	3	3Cu........	17	NE 10-15	0000 moonlight.
	0300	79.0	74.5	----	----	0	-	....	13	NE 8-10	0300 cloudy. 0555-0615 rain.
	0600	79.5	74.0	----	----	T	10	3Cu;10Ac....	16	NE 15*	0600 light rain.
	0900	76.5	74.5	----	----	0.04	10	4Cu;2Ac;6Cs	13	NE 14*	0905-0910 shwr. 1150-1155 shwr.
	1200	79.0	76.0	80.5	79.0	T	10	2Cu;8As....	16	NE 12*	1417-1425 shwr.
	1500	81.5	77.0	----	----	T	6	2Cu;4As....	15	NE 14*	
	1800	80.5	77.5	----	----	0	10	Cu,Sc.....	14	NE 17*	1730-1800 rain SE moving toSW; Cu 5 mile distant.
	2100	79.5	75.5	----	----	T	4	4Cu........	18	NE 15*	1821-1828 shwr. 2100 bright moon.
2/5	0000	79.5	75.5	81.5	79.0	0	8	Cu,Sc.....	17	NE 17*	0000 somewhat gusty.
	0300	79.5	74.5	----	----	0	9	Cu,Sc.....	18	NE 15*	0300 somewhat gusty.
	0600	79.0	75.0	----	----	0	8	8Cu........	18	NE 15*	0600 gusty.
	0900	80.0	74.5	----	----	0	6	6Cu........	18	NE 15*	0900 gusty.

PLACE: KEITH

THREE-HOURLY OBSERVATIONS, JANUARY 25 - FEBRUARY 8, 1958

TABLE 24 (Concluded)

Date and Time		TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	FF_3	DDFF	REMARKS
2/5	1200	83.5	74.0	83.5	78.5	0	1	1Cu........	17	NE 15*	
	1500	85.0	75.0	----	----	0	2	2Cu........	19	NE 15*	
	1800	82.0	74.0	----	----	0	3	3Cu........	17	NE 13*	
	2100	79.0	72.5	----	----	0	3	3Cu........	17	NE 15*	
2/6	0000	78.0	72.0	85.0	78.0	0	2	2Cu........	15	NE 14*	
	0300	78.0	70.0	----	----	0	0	....	16	NE 10*	0300 bright moonlight. 0450 rain. 0540-0612
	0600	75.0	72.5	----	----	0.04	10	10Sc.......	13	NE 9*	intermittent rain. 0625 rain began.
	0900	79.0	72.5	----	----	0.01	10	Cu,Sc.....	13	NE 15*	
	1200	82.5	74.0	82.5	75.0	0	5	3Cu;3Ac....	14	NE 10*	
	1500	81.5	72.0	----	----	0	0	0..........	16	NE 15*	
	1800	81.0	72.5	----	----	0	0	0..........	14	NE 12*	
	2100	79.0	72.0	----	----	0	0	0..........	14	NE 14*	
2/7	0000	78.5	72.5	82.5	78.5	0	5	5Cu;4Ci....	16	NE 19*	
	0300	78.0	72.0	----	----	0	5	5Cu........	16	NE 17*	0510 brief shwr.
	0600	78.0	72.5	----	----	T	8	8Cu........	16	NE 14*	0510-0530 gusty.
	0900	78.0	72.0	----	----	0	0	(Cu).......	18	NE 14*	
	1200	83.0	75.0	83.0	77.5	0	3	3Cu........	15	NE 14*	
	1500	84.0	75.0	----	----	0	3	3Cu........	17	NE 14*	
	1800	81.0	74.0	----	----	0	3	3Cu........	13	NE 14*	
	2100	78.5	74.0	----	----	0	0	0..........	14	NE 10*	
2/8	0000	78.5	73.0	86.0	78.5	0	5	5Cu........	15	NE 12*	
	0300	78.0	72.0	----	----	0	5	5Cu........	14	NE 10*	
	0600	78.0	72.0	----	----	0	9	7Cu;4Ci....	17	NE 12*	
	0900	82.0	74.0	----	----	0	5	1Cu;5Ci....	13	NE 14*	

PLACE: KEITH

HOURLY RELATIVE HUMIDITIES, JANUARY 25 - FEBRUARY 8, 1958*

TABLE 25

HOUR:	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400
DATE																								
1/25															72	--	--	78	--	--	83	--	--	81
1/26	--	--	80	--	--	77	--	--	72	--	--	68	--	--	67	--	--	74	--	--	74	--	--	77
1/27	--	--	83	--	--	75	--	--	74	--	--	67	--	--	64	--	--	68	--	--	71	--	--	71
1/28	--	--	79	--	--	75	--	--	68	--	--	66	--	--	64	--	--	67	--	--	68	--	--	77
1/29	--	--	79	--	--	83	--	--	78	--	--	65	--	--	62	--	--	73	--	--	79	--	--	79
1/30	--	--	87	--	--	87	--	--	74	--	--	69	--	--	63	--	--	73	--	--	82	--	--	84
1/31	--	--	87	--	--	85	--	--	82	--	--	72	71	70	74	70	74	82	85	84	83	85	86	81
2/1	85	92	90	89	89	89	85	86	94	90	86	68	62	64	65	70	76	80	84	86	87	90	91	96
2/2	90	90	88	92	90	83	83	82	82	84	92	87	88	80	74	74	81	78	85	86	78	79	76	75
2/3	75	75	75	76	76	77	79	78	78	76	82	74	77	77	71	75	75	76	79	78	78	80	80	79
2/4	80	80	82	80	79	78	98	92	91	92	90	87	86	82	81	86	86	87	91	88	89	89	89	89
2/5	90	91	80	81	82	83	82	81	77	74	70	64	64	64	63	64	66	69	74	73	73	72	76	75
2/6	77	70	67	74	86	88	86	80	74	73	72	67	68	68	63	--	--	67	--	--	71	--	--	75
2/7	--	--	75	--	--	77	--	--	75	--	--	69	--	--	66	--	--	72	--	--	81	--	--	77
2/8	--	--	75	--	--	75	--	--	69															

* Because of malfunctioning of the hygrothermograph, the hourly record is incomplete as shown.

PLACE: MACK DAILY OBSERVATIONS, JANUARY 25 - FEBRUARY 8, 1958 TABLE 26

DATE	TIME	TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	DDFF	SEA (Code)
1/25	1200	81.0	---	----	----	0	3	1Cu;2Ci.....	E 18-22	1
1/26	1200	80.0	---	81.0	78.5	0	1	1Cu;(Ci)....	NE 14-16	2
1/27	1200	79.5	---	80.5	76.0	0	1	1Cu;(Ac)....	NE 17-20	2
1/28	1200	80.5	---	80.5	78.0	T	7	6Cu;2Ci.....	NE 16	2
1/29	1150	80.0	---	81.0	78.0	0	5	5Cu;1Ci.....	NE 13-16	1
1/30	1200	79.5	---	80.5	74.0	0	4	(Cu);4CsCc..	E 5-7	1
1/31	1210	83.5	76.5	83.5	79.0	T	-	------------	----	---
2/1	1200	81.0	73.5	81.5	78.0	0.09	1	1Cu.........	NE 18-20	3
2/2	1200	81.0	74.5	81.0	75.5	0.75	10	10Cu,Sc.....	NE 20-25	4
2/3	1200	80.5	74.5	80.5	74.5	0.01	4	3Cu;2Ac.....	NE 18	3
2/4	1200	78.5	75.0	80.0	73.5	0.09	10	10Cu;(Ci)...	NE 12	2
2/5	1200	80.5	76.0	80.5	80.0?	0.01	2	2Cu.........	NE 18	2
2/6	1200	80.5	73.0	81.0	77.0	0	3	1Cu;3Ac.....	NE 14	2
2/7	1200	80.5	72.5	80.5	77.0	0	1	1Cu;1Ci.....	NE 13	2
2/8	0930	80.0	---	80.0	78.0	0	5	4Cu;1Ac;4Ci.	NE 12-15	1

REMARKS

1/25 Rainfall value covers period since 1400, 1/2/58.

1/26 Sea: Almost 2. Whitecaps barely forming.

1/27 Sea slight with whitecaps and with swells 4 feet.

1/28 Whitecaps barely forming.

1/29 Sea gentle, no whitecaps.

1/30 Banded Cc about 50° above SE horizon.

2/2 Wind seems to be increasing.

2/5 Sunny.

PLACE: MACK

BI-HOURLY TEMPERATURES AND RELATIVE HUMIDITIES, FEBRUARY 1 - 8, 1958

TABLE 27

HOUR:	0200		0400		0600		0800		1000		1200		1400		1600		1800		2000		2200		2400	
	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH	TT	RH
DATE																								
2/1											81	68	81	75	81	76	81	75	80	76	80	80	78	82
2/2	79*	83	78	83	80	75	80	75	80**	76	81	72	80	78	80	78	80	75	80	76	79	76	79	77
2/3	79	75	79	76	79	79	77***	78	79	78	79	80	80	75	80	75	80	78	80	78	79	80	79	78
2/4	79	77	79	79	79	81	74	88	76	82	78	83	79	83	76	85	80	82	80	79	80	81	80	83
2/5	80	80	79	81	79	76	79	78	80	77	80	72	80	75	80	75	80	78	79	75	79	75	79	72
2/6	78	70	78	78	77	78	79	76	79	71	79	75	79	70	79	74	80	65	79	74	79	76	78	77
2/7	78	80	78	80	78	79	79	70	80	75	80	72	79	78	79	82	79	79	79	81	79	80	79	79
2/8	79	78	79	77	78	76	79	76	80	76														

* Immediately after 0200, 2/2, temperature dropped sharply to 76°.

** Just before 1100, 2/2, temperature dropped sharply to 75°.

*** Just after 0700, 2/3, temperature was 76°.

PLACE: ELMER DAILY OBSERVATIONS, JANUARY 26 - FEBRUARY 7, 1958 TABLE 28

DATE	TIME	TT	TT_w	T_xT_x	T_nT_n	RR	N	C_{LMH}	DDFF
1/26	0900	81.0	74.0	85.0	69.0?	0	1	1Cu;(Ci).......	NE 10-12
1/27	1200	----	----	----	----	0	-	2Cu;4Ac........	NE 8-10
1/28	1200	----	----	83.5	79.0	0	4	3Cu;1Ci........	NE 8-10
1/29	1330	86.0	----	86.0	78.0	0	0	(Cu);(Ci)......	E 6-8
1/30	1200	86.5	----	87.5	76.0	0	4	2Cu;2Ac;1Ci....	NE 6
1/31	1200	85.0	----	90.5	78.0	0	5	5Cu............	NE 8-10
2/1	1200	85.0	75.0	88.0	76.0	0.09	0	(Cu)...........	E 12-15
2/2	1200	81.0	76.0	86.5	74.0	0.26	10	10Cu...........	E 15-18
2/3	1200	82.0	75.0	82.5	73.0	0.01	5	5Cu;1Ac........	NE 8-12
2/4	1200	82.0	76.0	83.0	74.5	0.03	5	2Cu;3Ac;3Cc,Ci.	NE 8-10
2/5	1200	86.0	76.5	84.5	78.0	0.04	2	2Cu............	E 12
2/6	1215	82.0	73.0	86.5	77.0	T	8	3Cu;5Sc........	NE 10
2/7	1320	84.5	74.5	85.0	75.0	0	3	3Cu............	NE 12

REMARKS

1/29	1330	Clear.
2/1	1200	Some cumulus on horizon. Towering cumulus on western horizon. Shwrs. from 0830-0840; 0915-0925. Brief intense shwr. about 0045.
2/2	1200	Rain at the following times: 2/1 2130-2145; 2330-2340. 2/2 0115-0200; 0245-0305; 0925-0945; 1130-1135; 1235-1245.
2/6	1215	Cloudy and bright. W-N horizon cloudless.

PLACE: JANET AND YVONNE

TABLE 29

DAILY RAINFALL, JANUARY 25 - FEBRUARY 8, 1958

DATE	TIME	RR JANET	TIME	RR YVONNE	REMARKS
1/25	0730	0*	1600	0*	* JANET total since 0730, 1/24; YVONNE total since 1652, 1/24/58.
1/26	1000	0	----	0	
1/27	0930	0	1600	0	
1/28	0730	0	1650	0	
1/29	0730	0	1640	0	
1/30	0730	0.36	1630	0	
1/31	0730	0.01	1650	T	
2/1	0730	0.05	1630	0.05	
2/2	----	**	***	0.20	** Amount included in next total.
2/3	0730	0.17	***	0.15	
2/4	0730	0	***	0.17	
2/5	0730	0.13	***	0.05	
2/6	0700	0	***	T	
2/7	0730	0	***	0	
2/8	0730	0	***	0	

*** About 1630

DATE	ZONE	TIME	TT_s	TIME	TT	TT_w	REMARKS
1/25		1031					Departed ELMER.
	1	1035	80.5*				Edge of deep water.
	2	1040	80.5*				Near stern of grounded barge.
	2	1056	80.5*				Off buoy "A".
	3	1115	80.5*				
	4	1135	80.5*				
	5	1150	81.0*				On outward trip, boat bore westerly, then north-easterly toward MACK; on return trip, it bore easterly and approached ELMER from NE.
		1155					Arrived MACK.
		1237					Departed MACK.
	5	1240	81.0*				
	4	1300	80.5*				
	3	1320	81.0*				
	2	1330	81.0*				Buoy "B".
	2	1350	80.5*				
	1	1402	80.5*				Edge of deep water.
		1405					Arrived ELMER.
1/26		1015					Departed ELMER.
	1	1017	80.5*				Edge of deep water.
	2	1038	80.5*				Off buoy "A".
	3	1057	80.5*				Near black unmarked buoy.
	4	1117	80.5*				
	5	1137	80.5*				300 yards from MACK.
		1142					Arrived MACK.
		1225					Departed MACK.
	5	1245	80.5*				
	4	1305	80.5*				
	3	1320	80.5*				
	2	1340	80.5*				300 yards from cement barge, near buoy "6".
	1	1347	80.5*				Edge of shallow water.
		1350					Arrived ELMER.
1/27		1024					Departed ELMER.
	1	1026	81.0*				Edge of deep water.
	2	1046	81.0*	1045	76.0		Buoy "A" 300 yards leeward and rear.
	3	1106	81.0*	1105	78.0		Buoy "11" 300 yards windward and rear.
	4	1126	81.0*	1125	77.0		OSCAR tower one mile windward.
	5	1146	81.0*	1145	79.0		MACK dead ahead 300 yards.
		1152					Arrived MACK.
		1243					Departed MACK.
	5	1245	81.0*	1244	77.0		200 yards off MACK.
	4	1305	81.0*	1304	79.0		OSCAR tower one mile.
	3	1325	81.0*	1324	79.5		
	2	1345	81.0*	1344	80.5		
	2	1405	81.0*	1404	80.5		
	1	1420	81.0*	1419	77.0		Edge of deep water.
		1425					Arrived ELMER.
1/28		1020					Departed ELMER.
	1	1024	81.0*	1023	81.0		Edge of deep water.
	2	1045	81.0*	1044	80.5		
	3	1104	81.0*	1103	80.0		Off buoy "11".
	4	1125	81.0*	1124	81.0		One mile W OSCAR tower.
	5	1142	81.0*	1141	80.0		200 yards off MACK.
		1148					Arrived MACK.
		1246					Departed MACK.
	5	1248	81.0*	1247	82.0		200 yards off MACK.

DATE	ZONE	TIME	TT_s	TIME	TT	TT_w	REMARKS
1/28	4	1312	81.0*	1311	81.5		One mile W OSCAR tower.
	3	1333	80.5*	1332	80.5		Buoy "11".
	2	1353	80.5*	1352	80.0		Buoy "A".
	1	1415	81.0*	1414	81.5		Edge of deep water.
		1420					Arrived ELMER.
1/29		1017					Departed ELMER.
	1	1020	81.7	1019	84.0		Edge of deep water.
	2	1042	81.3	1041	80.5		Four minutes past red buoy.
	3	1104	81.1	1103	81.0		
	4	1124	80.8	1123	81.0		
	5	1136	81.1	1135	80.5		200 yards off MACK.
		1140					Arrived MACK.
		1235					Departed MACK.
	5	1237	81.3	1236	82.0		200 yards off MACK.
	4	1258	81.3	1257	82.0		
	3	1317	81.1	1316	81.0		
	2	1338	81.1	1337	81.0		
	2	1400	81.1	1359	82.0		Buoy "8".
	1	1411	81.3	1410	82.0		Edge of shallow water.
		1415					Arrived ELMER.
1/30		1017					Departed ELMER.
	1	1020	81.5	1019	81.5	77.0	Edge of deep water.
	2	1040	81.5	1039	80.5	77.0	200 yards east of buoy.
	3	1100	80.6	1059	81.5	78.0	
	4	1120	80.6	1119	81.5	77.0	
		1137					Arrived MACK.
		1236					Departed MACK.
	5	1238	82.4	1237	81.5	78.0	200 yards off MACK.
	4	1300	81.5	1259	80.5	78.0	It was noted upon leaving MACK at 1236 that a
	3	1320	81.5	1319	80.5	77.0	mass of low cumulus had appeared and was
	2	1340	81.5	1339	80.5	78.0	moving in from SE. This Cu was not visible at 1200 from MACK. This Cu passed overhead and disappeared to NW by 1330.
	1	1357	81.5	1356	81.5	76.0	Edge of shallow water.
		1401					Arrived ELMER.
1/31		1002					Departed ELMER.
	1	1002	81.0*	1005	84.0	76.0	Edge of deep water.
	2	1021	81.0*	1024	82.5	76.0	Buoy "A".
	3	1040	81.0*	1044	82.0	76.0	Buoy "11".
	4	1059	81.0*	1102	82.5	76.0	1000 yards SE of OSCAR.
	5	1118	81.0*	1120	84.0	77.5	MACK.
				1120	83.5	76.5	MACK.
		1120					Arrived MACK.
		1215					Departed MACK.
	5	1218	81.0*	1220	82.5	77.0	200 yards off MACK.
	4	1238	81.0*	1240	83.5	77.5	2500 yards SE OSCAR.
	3	1257	81.0*	1300	82.5	77.0	700 yards S of buoy "11".
	2	1317	81.0*	1320	82.5	77.0	400 yards S of buoy "A".
	1	1340	81.5*	1342	83.5	77.0	Edge of deep water.
		1345					Arrived ELMER.
2/1		1017					Departed ELMER.
	1	1020	81.0*	1024	81.5	74.5	Edge of deep water. Light rain from 1020 to 1050. Sun out at 1055. During rain period 9Cu; state of sea 2.
	2	1040	81.0*	1043	80.0	75.5	150 yards N buoy "A".
	3	1058	80.0*	1103	79.0	75.0	Buoy "11".

DATE	ZONE	TIME	TT_s	TIME	TT	TT_w	REMARKS
2/1	4	1119	80.0*	1123	80.0	75.0	2000 yards S of OSCAR.
	5	1134	80.0*	1135	80.0	75.5	200 yards off MACK.
		1140					Arrived MACK.
		1248					Departed MACK.
	5	1250	80.5*	1254	81.0	74.0	200 yards off MACK.
	4	1310	80.0*	1312	81.0	74.0	2500 yards S of OSCAR.
	3	1333	80.5*	1335	81.0	74.0	Buoy "11".
	2	1355	81.0*	1358	80.5	74.0	Buoy "A".
	2	1413	81.0*	1415	80.5	73.5	Cement barge.
	1	1420	81.0*	1420	81.5	73.0	Edge of shallow water.
		1425					Arrived ELMER.
2/2		1014					Departed ELMER.
	1	1015	80.0*	1016	78.0	75.5	Edge of deep water.
	2	1030	80.0*	1029	79.0	76.0	Black buoy "7".
	3	1050	80.0*	1049	80.0	76.0	
	4	1110	80.0*	1109	79.5	75.0	
	5	1130	80.0*	1129	80.5	75.0	
		1140					Arrived MACK.
		1225					Departed MACK.
	5	1225	80.5*	1226	84.0	76.0	At MACK.
	4	1245	80.5*	1244	82.0	76.0	
	4	1305	80.0*	1304	81.0	75.5	
	3	1325	80.0*	1324	81.0	75.5	
	2	1345	80.0*	1344	80.0	76.5	
	1	1357	80.5*	1356	81.0	76.0	Edge of shallow water.
		1400					Arrived ELMER.
2/3		1016					Departed ELMER.
	1	1019	80.0*	1018	80.0	73.5	Edge of deep water.
	2	1040	80.0*	1039	79.5	75.5	Eleven minutes beyond buoy "8".
	3	1100	80.0*	1059	78.5	75.5	
	4	1119	80.0*	1118	78.0	73.5	
	5	1141	80.0*	1140	78.5	74.0	200 yards from MACK.
		1145					Arrived MACK.
		1240					Departed MACK.
	5	1243	80.0*	1242	80.0	75.5	200 yards from MACK.
	4	1305	80.0*	1304	80.5	75.0	
	3	1325	80.0*	1324	80.5	75.5	
	2	1347	80.0*	1346	80.5	75.0	
	2	1405	80.5*	1404	81.0	75.0	
	1	1418	80.0*	1417	81.0	75.0	Edge of deep water.
		1421					Arrived ELMER.
2/4		1023					Departed ELMER.
	1	1025	80.0*	1026	79.0	75.5	Edge of blue water.
	2	1045	80.0*	1047	79.0	75.5	200 yards N of buoy "A".
	3	1103	80.0*	1105	79.0	75.5	300 yards N of buoy "11".
	4	1125	80.0*	1128	79.0	75.5	1500 yards S of OSCAR.
	5	1138	80.0*	1140	80.0	75.5	200 yards off MACK. Rain shwr. at MACK from 1140 to 1150.
		1145					Arrived MACK.
		1245					Departed MACK.
	5	1248	81.0*	1250	80.0	76.0	100 yards off MACK. Rain shwr. from 1240 to 1250.
	4	1309	81.0*	1310	80.5	76.5	2500 yards SW of OSCAR.
	3	1326	81.0*	1328	80.5	76.0	500 yards NE of buoy "11".
	2	1345	80.0*	1346	79.5	76.0	300 yards NE of buoy "A".
	1	1405	80.0*	1405	79.0	75.0	Edge of blue water.
		1408					Arrived ELMER.

DATE	ZONE	TIME	TT_s	TIME	TT	TT_w	REMARKS
2/5		1010					Departed ELMER.
	1	1014	80.0*	1014	82.0	75.0	Edge blue water.
	2	1031	80.0*	1033	81.0	75.0	Buoy "A".
	3	1048	80.0*	1049	81.0	75.0	Buoy "11".
	4	1105	80.0*	1106	80.5	75.0	2000 yards S. of OSCAR.
	5	1120	80.0*	1121	81.0	74.0	150 yards S. of MACK.
		1130					Arrived MACK.
		1228					Departed MACK.
	5	1230	80.0*	1231	80.5	74.5	150 yards S. of MACK.
	4	1248	80.0*	1250	80.0	74.5	3 Miles S. of OSCAR.
	3	1305	80.0*	1307	80.0	74.0	Buoy "11".
	2	1323	80.0*	1325	80.0	74.5	Buoy "A".
	1	1342	80.0*	1342	82.0	74.0	Edge of blue water.
		1344					Arrived ELMER.
2/6		1014					Departed ELMER.
	1	1016	80.0*	1016	80.0	72.5	Edge of deep water.
	3	1036	80.0*	1036	80.5	73.0	Off buoy "11".
	4	1056	80.0*	1056	80.0	71.5	
	4	1115	80.0*	1115	80.0	72.5	7 minutes SW of OSCAR.
	5	1140	80.0*	1140	79.5	72.5	200 yards off MACK.
		1145					Arrived MACK.
		1241					Departed MACK.
	5	1244	81.0*	1244	83.0	74.5	200 yards off MACK. Rain 1259-1301.
	4	1303	80.5*	1303	82.5	74.5	1 mile WSW of OSCAR.
	3	1323	80.5*	1323	82.5	73.5	
	3	1344	80.0*	1344	83.0	72.0	Off buoy "11".
	1	1410	80.0*	1410	83.0	73.5	Edge of deep water.
		1412					Arrived ELMER.
2/7		1016					Departed ELMER.
	1	1019	80.0*	1019	81.0	73.0	Edge deep water.
	2	1038	80.0*	1038	81.0	73.5	Off buoy "8".
	3	1059	80.0*	1059	80.5	73.0	
	4	1120	80.0*	1120	80.5	73.0	1 mile W of OSCAR.
	5	1136	80.0*	1136	80.5	73.5	200 yards off MACK.
		1139					Arrived MACK.
		1225					Departed MACK.
	5	1227	81.0*	1227	81.5	74.0	200 yards off MACK.
	4	1247	80.5*	1247	82.0	74.0	1 mile off OSCAR.
	3	1307	80.5*	1307	82.5	74.0	
	2	1328	80.5*	1328	82.0	74.5	100 yards N of buoy "10".
	1	1345	80.0*	1345	83.0	74.5	Edge of deep water.
		1348					Arrived ELMER.

LAGOON TRAVERSES, FEBRUARY, 1958

Traverse No. 1, BRUCE-KEITH

DATE	TIME	TT_s	TIME	TT	TT_w	REMARKS
1st	1010					Departed BRUCE.
	1012	80.0*	1014	80.5	75.0	Edge of deep water at BRUCE.
	1030	80.5*	1035	80.5	75.0	
	1040	80.5*	1042	80.0	75.0	10 yards off buoy "B".
	1100	80.5*	1103	79.0	75.0	Immediately after light rain shwr.
	1120	80.5*	1123	81.0	75.5	
	1139	80.5*	1141	81.5	76.0	
	1155	80.5*	1157	83.0	75.5	
	1202	80.5*	1204	80.5	74.5	Edge of deep water at KEITH.

Traverse No. 2, BRUCE-KEITH-ELMER

DATE	TIME	TT_s	TIME	TT	TT_w	REMARKS
7th	0934	79.0*	0934	80.5	73.0	15 yards off BRUCE. Departing for KEITH.
	0937	79.5*	0937	80.5	73.0	Edge of deep water.
	0957	80.0*	0957	81.5	74.5	
	1017	80.0*	1017	80.5	73.0	
	1037	80.0*	1037	80.5	73.5	
	1057	80.0*	1057	80.0	72.5	
	1114	80.0*	1114	81.0	74.0	Edge of deep water.
	1116	79.5*	1116	81.0	73.0	Between buoys.
	1117					At KEITH departing for ELMER.
	1137	80.0*	1137	81.0	73.5	
	1157	80.0*	1157	81.0	73.5	
	1217	80.0*	1217	81.5	74.0	
	1237	80.0*	1237	81.0	74.0	
	1258	80.5*	1258	81.5	74.0	Edge deep water off ELMER.
	1300					Arrived ELMER.

LAGOON-OCEAN TRAVERSE, FEBRUARY, 1958

DATE	TIME	TT_s	TIME	TT	TT_w	REMARKS
6th	0850					Departed FRED.
	0854	80.0*		80.5	74.5	Edge of deep water.
	0908	80.0*		80.0	73.5	Between channel marker buoys in the South Channel.
	0915	80.0*		80.0	74.0	Outside, end of five minute run on Course 190° magnetic.
	0926	80.0*		80.0	74.0	Outside, end of ten minute run around west side of the reef.
	0938	80.0*		80.0	74.5	Outside, off KEITH.
	0950	80.0*		80.5	74.5	Outside, NW of KEITH.
	1004	80.0*		80.0	74.5	Outside, off KEITH.
	1016	80.0*		79.5	74.0	Outside, between KEITH and South Channel.
	1039	80.0*		81.0	74.5	Between channel marker buoys in the South Channel.
	1058	80.0*		80.0	72.0	Off FRED (northern end) approximately one mile in lagoon.
	1108	80.0*		81.0	73.0	Edge of deep water off ELMER by the personnel pier.
	1115					Arrived ELMER. Water temperatures outside the lagoon were a little over 80.0 and inside were a little under 80.0°F.

Part D. Observational Data for Extensive Phase

(September, 1957 -- August, 1958)

NOTES: TABLES 33-38

For comments regarding raingage locations and relative accuracy of Gages 1 and 2 on FRED, see General Notes, p. 28. For comments regarding bias of raingage readings on MACK, see Notes for Table 10, p. 44.

In general, all rainfall observations in these Tables are correct to 0.01 inch. Times are correct within 10 minutes, except that the 0000 time for rainfall observations at FRED is correct within 3 minutes.

PLACE: FRED

DAILY RAINFALL ENIWETOK

	1957					1958							
	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
1	0.06	0.02	0.02	0.15	0.01	0.22	0.04	T	T	1.57	0.01	0.01	T
2	0.01	0.04	T	0.21	0.05	0.36	0.05	1.03	0.28	0.14	0.02	0.01	T
3	0.05	0.08	T	0.12	T	0.03	T	0.01	0.05	T	T	0.30	T
4	0	0.54	0.28	0.01	0.01	0.03	T	T	T	0.07	0.05	0.45	0
5	0.14	0.12	0.16	2.37	0.96	0	T	0.08	0.07	T	0.13	0.30	T
6	T	0	0	0.15	0	0.05	T	T	T	0	0.02	0.01	0.06
7	0.05	T	0.08	0.02	0.02	T	T	T	T	0	0.06	T	T
8	0.19	1.30	0	0.26	0.03	0.05	0	0.08	0.01	T	0	0.02	0.45
9	0	T	T	0.02	1.04	0.06	0.02	0.11	T	T	T	0.09	0.19
10	0	0.30	0.89	0.08	0	0.19	0	0.05	0.57	T	T	0.11	0.68
11	0.01	T	T	0.18	T	0	0.02	T	0.12	0.10	T	0.23	1.32
12	0	0.15	3.04	1.78	T	0	0.01	0.03	T	0	1.21	T	0.29
13	0.14	T	0.02	5.28	T	0.01	0	T	0	0.06	0.05	1.16	0.02
14	0.35	0.08	0.30	T	T	0.12	0	0.06	0.06	0	T	0.44	T
15	1.50	0.11	0.54	0.06	0.01	T	0.31	0	0.39	0	0.24	1.09	1.06
16	0.02	0.01	0.02	0	0.06	T	0	0	0.02	0	0.01	2.52	0.67
17	0.15	0	0.03	0	T	0.02	T	0	T	0.27	0	T	0.27
18	0	0.03	0.14	0.90	T	T	0	T	0.05	T	T	2.61	0.08
19	0	T	0.15	T	0.05	0	T	0.05	0.08	0.18	T	0.13	0.14
20	0	0.25	0	0.01	0.25	T	0	T	0.01	T	T	T	0.61
21	0.15	T	0.02	0	0	0.63	T	0.13	0.01	T	T	0.81	0.41
22	0.01	T	0	0.02	0	0.10	0	0	0.07	0	T	4.43	T
23	0.41	0	0.79	0.08	0	0	0	0	0.23	T	T	0.31	0.94
24	0.05	0.15	0.11	0.14	0	0	T	0	T	0.01	0.26	T	0.09
25	0	T	0.13	0.12	0	T	0.01	T	T	0	0.09	0.01	0.02
26	0.02	0.01	0.79	0.08	0.01	0	0	0	0	0	0.05	0.21	0.12
27	0.50	0.01	0.31	0.06	0	0	0	T	T	T	T	0	0.01
28	0	0.32	0	0.01	0.04	T	0	0	0	T	0.23	T	0.13
29	0.01	0.10	0.34	0.01	T	0		0.01	0	0.02	0.06	0	0.12
30	0.32	0.10	0.06	0.20	0.05	0		T	0.03	0.22	0.05	0.10	0.02
31	0.06		T		0.04	T		0.08		0.75		T	0.12
MONTHLY TOTAL	4.28	3.72	8.22	12.32	2.63	1.87	0.46	1.72	2.05	3.39	2.54	15.35	7.82

PLACE: FRED

COMPARATIVE RAINFALL OBSERVATIONS,
AUGUST, 1957 - JANUARY, 1958

TABLE 34

DATE OF READING	TIME OF GAGE #1 READING	GAGE #1	GAGE #2**
8/18/57	1215	0	0
8/19	1200	0	0
8/20	1200	0	0
8/21	1200	0.15	0.15
8/22	1200	0.15	0.01
8/23	1200	0.05	0.41
8/24	1200	0.50	0.05
8/25	1200	0	0
8/26	1200	0.01	0.02
8/27	1200	0.52	0.50
8/28	1200	0.55	0
8/29	1200	0.01	0.01
8/30	1200	0.35	0.32
8/31	----	0.35	0.06
9/1	0904	0***	0.02
9/2	0900	0	T
9/3	0900	0	T
9/4	0900	0.69	0.54
9/5	0900	0.60	0.12
9/6	0855	0.80	0
9/7	0900	0	T
9/8	0900	1.00	1.30
9/9	0900	0.50	T
9/10	0900	0.23	0.30
9/11	0850	T	T
9/12	0900	0.17	0.15
9/13	0900	T	T
9/14	0900	T	0.08
9/15	0900	0.20	0.11
9/16	0910	0.11	0.01
9/17	1000	T	0
9/18	0915	0	0.03
9/19	0910	0.81	T
9/20	0900	0.30	0.25
9/21	0900	0.01	T
9/22	0920	0.01	T
9/23	0905	T	0
9/24	0915	0.15	0.15
9/25	0900	0.01	T
9/26	1300	0.01	0.01
9/27	0900	0	0.01
9/28	0900	0.03	0.32
9/29	0905	0.41	0.10
9/30	1040	0.12	0.10
10/1	0905	0.06	0.02
10/2	0900	0	T
10/3	0900	T	T
10/4	0900	0.12	0.28
10/5	Break in record, Gage #1		
11/1	1300	0.03	0.15
11/2	0900	0.20	0.21
11/3	1030	0.15	0.12
11/4	0855	0.10	0.01
11/5	0855	0.37	2.37
11/6	----	*	0.15
11/7	0900	1.97	0.02
11/8	0855	0.25	0.26
11/9	----	*	0.02
11/10	0925	0.05	0.08
11/11	0930	0.10	0.18

DATE OF READING	TIME OF GAGE #1 READING	GAGE #1	GAGE #2**
11/12/57	0900	1.80	1.78
11/13	0855	0.16	5.28
11/14	0925	1.96	T
11/15	0900	0.05	0.06
11/16	0905	T	0
11/17	----	*	0
11/18	----	*	0.90
11/19	0906	3.68	T
11/20	0900	0.02	0.01
11/21	0900	0	0
11/22	0900	0	0.02
11/23	1600	0.03	0.08
11/24	1600	0.25	0.14
11/25	0900	1.04	0.12
11/26	0900	0.06	0.08
11/27	0900	0.30	0.06
11/28	0900	T	0.01
11/29	0855	0.02	0.01
11/30	1800	0.25	0.20
12/1	0930	0.01	0.01
12/2	0855	0.06	0.05
12/3	0905	T	T
12/4	0858	T	0.01
12/5	0930	0.73	0.96
12/6	----	*	0
12/7	1100	0.02	0.02
12/8	----	*	0.03
12/9	0900	0.81	1.04
12/10	0900	0.23	0
12/11	----	*	T
12/12	0900	T	T
12/13	0900	0	T
12/14	0900	T	T
12/15	----	*	0.01
12/16	0900	T	0.06
12/17	0900	0.06	T
12/18	0900	T	T
12/19	0900	0.05	0.05
12/20	0900	T	0.25
12/21	0855	0	0
12/22	Break in record, Gage #1		
1/1/58	0900	0.26	0.22
1/2	0900	0.15	0.36
1/3	0900	0.21	0.03
1/4	0900	0.06	0.03
1/5	0900	0	0
1/6	0900	0	0.05
1/7	0900	0.05	T
1/8	0900	T	0.05
1/9	0900	0.03	0.06
1/10	0900	0.06	0.19
1/11	0900	0.19	0
1/12	0900	0	0
1/13	0900	0	0.01
1/14	0900	0.04	0.12
1/15	0900	0.09	T
1/16	0900	T	T
1/17	0900	0.02	0.02
1/18	0900	T	T

DATE OF READING	TIME OF GAGE #1 READING	GAGE #1	GAGE #2**
1/19/58	0900	0	0
1/20	0900	T	T
1/21	0900	0.01	0.63
1/22	0900	0.64	0.10
1/23	0900	0.06	0
1/24	0900	0	0
1/25	0900	T	T
1/26	0900	0	0
1/27	0900	0	0
1/28	0900	0.01	T
1/29	0900	0	0
1/30	0900	0	0
1/31	0900	0	T

* Amount included in next total.

** 24 hour rainfall ending 2400 (180th meridian) on the date shown.

*** Not measured but believed to be zero.

PLACE: BRUCE, KEITH, MACK

OCCASIONAL RAINFALL OBSERVATIONS, SEPTEMBER, 1957 - AUGUST, 1958

TABLE 35

BRUCE				KEITH			MACK		
DATE	TIME	RR_L*	RR_O*	DATE	TIME	RR*	DATE	TIME	RR*
9/16/57	0845	---	3.15(1)	9/15/57	1000	2.30(1)	9/14/57	1000	1.71(4)
10/1/57	0900	---	2.14	9/30/57	1130	2.14	10/1/57	1045	1.54
10/15/57	1100	---	3.37	2/28/58	1030	0.16(3)	10/15/57	0920	3.41
10/31/57	1100	3.30(2)	3.27	3/15/58	0930	0.87	10/31/57	0930	3.35
11/16/57	1200	3.92	4.11	4/15/58	0930	2.00	11/16/57	1000	3.48
11/27/57	1140	0.31	0.28	4/30/58	----	0.42	12/3/57	1400	1.80
12/16/57	0840	0.11	0.11	5/31/58	----	0.34	12/16/57	1000	0.10
1/2/58	1530	0.10	0.09	7/15/58	----	3.10	1/2/58	1402	0.08
1/15/58	1010	1.24	1.32	7/30/58	----	9.39	1/15/58	0850	1.30
2/18/58	0850	0.24(3)	0.26(3)	8/15/58	----	4.85	2/18/58	0900	0.35(5)
3/7/58	1305	0.24	0.25	8/30/58	----	4.00	3/6/58	1230	0.15
3/21/58	0935	0.50	0.50				3/17/58	1130	1.20
3/31/58	1040	0.10	0.12				3/31/58	1335	0.06
4/21/58	1000	2.60	2.65				4/16/58	----	1.60
6/2/58	1000	4.02	4.10						
6/30/58	0950	2.43	2.35						
8/1/58	1000	9.92	10.80						
8/30/58	1300	5.95	5.98						

FOOTNOTES

(1) Total rainfall since 0900, 9/1.
(2) Total rainfall since 1100, 10/15.
(3) Total rainfall since 0900, 2/8.
(4) Total rainfall since 1145, 8/31.
(5) Total rainfall since 0930, 2/8.
* Rainfall total since last observation.

PLACE: ELMER

TABLE 36

DAILY RAINFALL**

	1957					1958						
	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
1	*	0.13	0.24	*	0.30	0.09	0	*	1.85	*	0	0.10
2	*	0	0.10	*	0.20	0.26	*	*	0.04	0.75	0.06	*
3	0.84	0.21	*	0	0.18	0.01	0.05	0.13	0	0.02	0	*
4	0.04	0	0.10	0.05	0.10	0.03	0	0	*	0.01	*	0.18
5	0.10	0.16	1.40	0.21	*	0.04	0	0.03	0	0.18	0.99	0
6	0.27	0.10	0.45	0.01	0.06	T	0.02	*	0.01	0	*	0.01
7	0.11	0.15	0.40	0.01	0.09	0	0	0.05	0	0	0.05	*
8	0.48	0	0.04	0.06	0.15	*	0	0.01	0	*	0	1.58
9	0.51	0	0.01	0.04	0.25	*	*	0	0	0	0.23	0.42
10	0.52	0.06	*	*	0.26	*	0.15	0.37	0.01	0	0.27	*
11	0.04	0.13	0.12	0.07	0.24	0.01	0.01	0.63	*	0	0.15	1.07
12	0.02	0.02	2.75	0.07	*	0.01	0.01	0.07	0.04	0.73	0.02	0.60
13	0	*	0.08	0.07	0.23	0	0.04	*	0	0.01	*	0
14	0	2.25	0.14	0	0.32	0	0	0.01	0.05	0.01	1.28	*
15	0.11	1.05	0.10	*	0.32	0	0	0.36	0	*	0.59	0.21
16	0.07	0.01	*	0.06	0.20	*	*	0.05	0	0.60	3.63	0.38
17	0	0.29	0	0.04	0.18	0.20	0	0	0	*	0.10	*
18	0.01	0.01	0	0.06	0.10	0	0.01	0	*	0	0.83	0.45
19	0.01	0.04	***	0.16	*	0	0.01	0.09	0.15	0	0	0.07
20	0.07	*	***	0.09	0.05	0	0	*	0	0.01	*	0.19
21	0.01	0.03	***	0.06	0.40	0	0	0.12	0	0	0.10	*
22	0.03	0	***	*	0.40	0	0	0.04	0	*	2.61	0.97
23	0.15	1.57	***	0.01	0.35	*	*	0.21	*	0.01	0.13	0.62
24	0.12	0.09	***	0	0.30	0	0	0.03	0	0.20	0.34	*
25	0	0.02	***	*	0	0	0	0.02	*	0.04	*	0.25
26	0.16	0.98	***	0	0	0.01	0	0	*	*	0.02	0.03
27	0.17	*	***	0	0	0	0.01	*	*	0.04	*	0.05
28	0.64	1.00	***	0.05	0	0	0	0	0	0	0	0
29	0.17	1.07	0.64	*	0		0.01	0	0.02	*	*	0
30	0.43	0.80	0.02	0.10	0		*	0	*	0.52	0.01	0.34
31		0.01		0.06	0		0		*		0.26	0.19

* Amount included in next total.
** For times of observations, see NOTES.
*** Installation damaged by typhoon. Placed back in operation 11/28/57.

PLACE: JANET DAILY RAINFALL, AUGUST 30, 1957 - APRIL 29, 1958 TABLE 37

DATE	TIME	RR	DATE	TIME	RR	DATE	TIME	RR	DATE	TIME	RR
8/30/57	0915	0.15**	11/5/57	0800	0.41	1/8/58	0730	0	3/13/58	0730	0.09
8/31	0915	0.01	11/6	0730	3.03	1/9	0730	0.08	3/14	----	*
9/1	----	*	11/7	0730	0.31	1/10	0730	0.05	3/15	0730	0.23
9/2	----	*	11/8	0730	0.34	1/11	0730	0	3/16	1000	0
9/3	0915	0.63	11/9	0730	0.03	1/12	0930	0	3/17	0730	0
9/4	0915	0.05	11/10	0930	0.02	1/13	0730	0	3/18	0730	0.06
9/5	0915	0.01	11/11	0730	0.02	1/14	0730	0.19	3/19	0730	0.06
9/6	0915	0.00	11/12	0730	1.45	1/15	0730	0.06	3/20	0730	0.03
9/7	0915	0.01	11/13	0730	0.06***	1/16	0730	0.01	3/21	0730	0
9/8	----	*	11/14	0730	0.88	1/17	0730	0.08	3/22	0730	0
9/9	0915	0.39	11/15	0730	0.04	1/18	0730	0.08	3/23	1100	0
9/10	0915	0.01	11/16	0730	0.12	1/19	0930	0	3/24	0730	0
9/11	0915	0.11	11/17	0930	0	1/20	0730	0	3/25	0730	0.03
9/12	0915	0.05	11/18	0730	0	1/21	0730	0.12	3/26	----	*
9/13	0915	0	11/19	0730	1.53	1/22	0730	0.07	3/27	0730	0
9/14	0915	0	11/20	0730	0.04	1/23	0730	0.04	3/28	0730	0
9/15	----	*	11/21	0730	0	1/24	0730	0	3/29	0730	0
9/16	0915	0.01	11/22	0730	0	1/25	0730	0	3/30	----	*
9/17	0915	0	11/23	0730	0.07	1/26	1000	0	3/31	0730	0
9/18	0915	0.01	11/24	0730	0.56	1/27	0930	0	4/1	0730	0.07
9/19	0915	0	11/25	0730	0.13	1/28	0730	0	4/2	0730	0.01
9/20	0915	0.03	11/26	0730	0.01	1/29	0730	0	4/3	0730	1.12
9/21	0915	0.31	11/27	0730	0.06	1/30	0730	0.36	4/4	0730	0.08
9/22	----	*	11/28	0730	0.34	1/31	0730	0.01	4/5	0730	0
9/23	0915	0.33	11/29	0730	0.26	2/1	0730	0.05	4/6	----	*
9/24	0915	0.22	11/30	0730	0.29	2/2	----	*	4/7	0730	0.24
9/25	0915	0.25	12/1	0930	0	2/3	0730	0.17	4/8	0730	0.12
9/26	0915	0.02	12/2	0730	0.01	2/4	0730	0	4/9	0730	0
9/27	0915	0.20	12/3	0730	0	2/5	0730	0.13	4/10	0730	0
9/28	1615	0.14	12/4	0730	0.14	2/6	0700	0	4/11	0730	0.12
Break in record.			12/5	0730	0.26	2/7	0730	0	4/12	0730	0.37
Rainfall unknown.			12/6	0730	0.22	2/8	0730	0	4/13	0730	0
10/4	0730	0.13**	12/7	0730	0	2/9	1000	0	4/14	0730	0
10/5	0730	0.01	12/8	0930	0.16	2/10	0730	0	4/15	0730	0.17
10/6	----	*	12/9	0730	0.14	2/11	0730	0.23	4/16	0730	0.11
10/7	0730	1.45	12/10	0730	0.16	2/12	0730	0.08	4/17	0730	0.02
10/8	0730	0	12/11	0730	0	2/13	0730	0	4/18	0730	0
10/9	0730	0	12/12	0730	0.08	2/14	0730	0.07	4/19	0730	0.12
10/10	0730	0.18	12/13	0730	0	2/15	0730	0	4/20	----	*
10/11	0730	0.06	12/14	0730	0	2/16	0930	0	4/21	0730	0.11
10/12	0730	0	12/15	0930	0	2/17	0730	0.07	4/22	0730	0
10/13	0930	1.09	12/16	0730	0.03	2/18	0730	0	4/23	0730	0.18
10/14	0730	0.17	12/17	0730	0	2/19	0730	0	4/24	0730	0.01
10/15	0730	2.42	12/18	0730	0.02	2/20	0730	0	4/25	0730	0.01
10/16	0730	0.01	12/19	0730	0.36	2/21	0730	0	4/26	0730	0.06
10/17	0730	0.11	12/20	0730	0	2/22	0730	0	4/27	0730	0
10/18	0730	0.12	12/21	0730	0.08	2/23	0930	0	4/28	0730	0
10/19	0730	0.03	12/22	0930	0	2/24	0730	0	4/29	0730	0
10/20	0900	0.15	12/23	0730	0	2/25	0730	0			
10/21	0730	0	12/24	0730	0	2/26	0730	0.08			
10/22	0730	0	12/25	1100	0	2/27	0730	0			
10/23	0730	0.44	12/26	0730	0.03	2/28	0730	0			
10/24	0730	0.25	12/27	0730	0.02	3/1	0730	0			
10/25	0730	0.46	12/28	0730	0.01	3/2	----	*			
10/26	0730	0.17	12/29	0930	0.14	3/3	0700	0.29			
10/27	0930	0.12	12/30	0730	0	3/4	0730	0.02			
10/28	0730	0.01	12/31	0730	0.02	3/5	0730	0.05			
10/29	0730	0.09	1/1/58	0730	0.40	3/6	0730	0.02			
10/30	0730	0.16	1/2	0730	0.02	3/7	0730	0.11			
10/31	0730	0.03	1/3	0730	0.07	3/8	----	*			
11/1	0730	0.05	1/4	0730	0.01	3/9	1000	0			
11/2	0730	0.25	1/5	0930	0.06	3/10	0730	0.01			
11/3	0930	0.01	1/6	0730	0	3/11	0730	0			
11/4	0730	0.01	1/7	0730	0.12	3/12	0730	0.29			

* Amount included in next total.

** Amount in last 24 hours.

*** Gauge was covered when checked. Doubtful value.

PLACE: YVONNE DAILY RAINFALL, FEBRUARY 8 - APRIL 21, 1958 TABLE 38

FEBRUARY	TIME	RR	MARCH	TIME	RR	APRIL	TIME	RR
			1	1650	0	1	1700	0
			2	1600	T	2	1700	0
			3	1600	0.02	3	1700	0.02
			4	1650	0.06	4	1700	0.03
			5	1600	0	5	1700	0.12
			6	1650	0.02	6	1700	0.22
			7	1600	0	7	1700	0.07
8	**	0	8	1630	0.07	8	1700	0
9	----	*	9	----	*	9	1700	0.10
10	1640	0	10	1620	0.04	10	1700	0.50
11	1500	0.07	11	1650	0.05	11	1700	1.45
12	1655	0.08	12	1630	0.03	12	1700	0
13	1655	0	13	----	*	13	1700	0
14	1655	T	14	1630	0.07	14	1700	0.34
15	1650	0	15	1630	0	15	1700	0.30
16	----	*	16	1650	0.01	16	1700	0.03
17	1640	0	17	1750	0.07	17	1700	0
18	1650	0	18	1700	0	18	1700	0.02
19	1640	0	19	1715	0.20	19	1700	0.18
20	1650	0	20	1640	0	20	1700	0.10
21	1640	0	21	1700	0	21	1700	0
22	1650	T	22	1710	0			
23	----	*	23	1700	0			
24	1630	T	24	1715	0			
25	1600	0.07	25	1710	0			
26	1650	0.03	26	1700	0			
27	1600	0	27	1700	0			
28	1610	T	28	1720	T			
			29	1700	0			
			30	1640	0.01			
			31	1700	0			

** Time of observation about 1630.

* Amount included in next reading.

APPENDICES II AND III

APPENDIX II.

INDICES FOR PHOTOGRAPHS

CONTENTS

NOTES: TABLES A THROUGH F

GENERAL: Photographs listed in this Appendix can be borrowed for scientific use for a period that will be expected not to exceed 30 days. Requests for photographs on loan should be addressed to the U. S. Weather Bureau, Washington 25, D. C., Attention: Public Information Coordinator. In ordering photographs refer specifically to MICROCLIMATIC OBSERVATIONS AT ENIWETOK, distinguish specifically between Radarscope and Cloud photos, and list the photos required both by dates and by index numbers.

TABLES A AND B. On these photos, true north is directly at the top. The range is 75 miles. Times are correct within 5 minutes.

TABLES C THROUGH F. The camera was hand-held, with orientation usually determined by markers that had been established using a Brunton compass. Directions given are true and are estimated to be correct within 10° (plus or minus). It will be noted that the standard directions were so selected that one of the pairs of photographs from BRUCE was taken facing KEITH and the other was taken 90° clockwise from this direction. Similarly, one of the photographs from KEITH was normally taken facing BRUCE, and the other was taken 90° clockwise from this direction. Directions other than these standard ones were used primarily to avoid having to take a photograph directly into the sun. Quality of the photographs varies. All photos indexed are sufficiently clear to show the general form of the clouds (if any) and the general amount of cloud within the view of the camera (not including high, thin cirrus). However, the photos whose quality is only fair are not sufficiently sharp to discriminate between cloud types that sometimes closely resemble one another, as between cumulus and marginal forms of strato-cumulus (cumulus with some stratification). Times given refer to 180th meridian and are correct within 5 minutes.

PLACE: FRED INDEX NUMBERS OF RADARSCOPE PHOTOS, AUGUST 18 - SEPTEMBER 1, 1957* TABLE A
(Eniwetok dates and times - 180th meridian)

TIME	DATE														
	18th	19th	20th	21st	22nd	23rd	24th	25th	26th	27th	28th	29th	30th	31st	1st
0000	----	----	----	16	----	32	----	----	----	71	76	98	122	----	----
0015	----	----	----	17	----	33	42	----	----	----	77	99	123	----	----
0245	----	----	----	18	----	34	43	----	----	----	78	100	124	----	----
0300	----	----	----	19	----	35	44	----	----	----	79	101	125	----	----
0315	----	----	----	20	----	36	45	----	----	----	80	102	126	----	----
0545	----	----	----	21	----	37	46	----	----	----	----	103	127	135	----
0600	----	----	----	22	----	38	47	----	----	----	----	104	128	136	----
0615	----	----	----	23	----	39	48	----	----	----	81	105	129	137	----
0845	----	----	6	24	----	40	49	----	----	----	82	106	130	138	----
0900	----	----	7	25	----	41	50	----	----	----	83	107	131	139	153
0915	----	----	8	26	----	----	51	----	----	----	84	108	132	140	154
1145	----	----	9	27	----	----	52	----	----	----	85	109	133	141	----
1200	----	----	----	28	----	----	53	----	----	----	86	110	----	142	----
1215	----	----	10	29	----	----	54	----	60	72	87	111	----	143	----
1445	----	1	----	----	----	----	55	----	61	73	88	112	----	144	----
1500	----	2	----	----	----	----	56	----	62	74	89	113	134	145	----
1515	----	3	----	----	----	----	57	----	63	75	90	114	----	146	----
1745	----	----	----	----	----	----	58	----	64	----	91	115	----	147	----
1800	----	4	----	----	----	----	59	----	65	----	92	116	----	148	----
1815	----	5	11	----	----	----	----	----	66	----	93	117	----	----	----
2045	----	----	12	----	----	----	----	----	67	----	94	118	----	149	----
2100	----	----	13	----	30	----	----	----	68	----	95	119	----	150	----
2115	----	----	14	----	31	----	----	----	69	----	96	120	----	151	----
2345	----	----	15	----	----	----	----	----	70	----	97	121	----	152	----

* Blanks indicate no photograph was obtained.

PLACE: FRED INDEX NUMBERS OF RADARSCOPE PHOTOS, JANUARY 25 - FEBRUARY 8, 1958* TABLE B

(Eniwetok dates and times - 180th meridian)

TIME	DATE													
	25th	26th	27th	28th	29th	30th	31st	1st	2nd	3rd	4th	5th	6th	7th	8th
0000	----	213	234	----	279	301	316	340	357	380	402	423	445	----	----
0015	----	214	235	----	280	----	317	341	358	381	403	424	446	----	----
0245	----	215	236	257	281	302	318	342	359	382	404	425	447	----	----
0300	----	216	237	258	282	----	319	----	360	383	405	426	448	----	----
0315	----	217	238	259	283	----	320	343	361	384	406	427	----	----	----
0545	----	218	239	260	284	303	321	----	362	385	407	428	449	----	----
0600	----	219	240	261	285	304	322	344	363	386	408	429	450	----	----
0615	----	220	241	262	----	305	323	345	364	387	409	430	451	----	----
0845	----	221	242	263	286	306	324	----	365	388	410	431	----	----	----
0900	----	222	243	264	287	307	325	----	366	389	411	432	----	----	----
0915	----	223	244	265	288	308	326	346	367	390	412	433	----	----	----
1145	201	224	245	266	----	309	327	347	368	391	----	434	----	----	----
1200	202	225	246	267	289	310	328	348	369	392	413	----	----	----	----
1215	203	226	247	268	290	----	329	----	370	393	414	435	----	----	----
1445	204	227	248	269	291	----	330	----	371	394	----	436	----	----	----
1500	205	----	249	270	292	----	331	349	372	395	415	437	----	----	----
1515	206	----	250	271	293	311	332	----	373	396	416	438	----	----	----
1745	207	228	251	272	294	----	333	350	374	----	417	439	----	----	----
1800	208	----	252	273	295	----	334	351	375	397	418	----	----	----	----
1815	209	229	253	274	296	----	335	352	----	398	419	440	----	----	----
2045	----	230	254	275	297	312	336	353	376	----	----	441	----	----	----
2100	210	231	255	276	298	313	337	354	377	399	420	442	----	----	----
2115	211	232	256	277	299	314	338	355	378	400	421	443	----	----	----
2345	212	233	----	278	300	315	339	356	379	401	422	444	----	----	----

* Blanks indicate no photograph was obtained.

PLACE: BRUCE

INDEX NUMBERS FOR CLOUD PHOTOGRAPHS, SERIES A,
AUGUST 21 - 31, 1957**
(Degrees show direction in which camera was pointed.)

TABLE C

HOUR:***	0600	0900	1200	1500	1800
DATE					
21	0655: 331° B2-9*		241° B3-3* 331° B3-4	241° B3-5 331° B3-6	241° B3-7 331° B3-8
22	0645: 241° B3-11	241° B3-12	241° B4-1* 331° B4-2	241° B4-3 331° B4-4	241° B4-5 331° B4-6
23	0645: 241° B4-7* 331° B4-8		241° B4-9 331° B4-10*	241° B4-11 331° B4-12	241° B4-13 331° B4-14
24	0645: 241° B4-15 331° B4-16	241° B4-17* 331° B4-18*	241° B4-19	241° B5-1 331° B5-2	241° B5-3 331° B5-4*
25	0620: 241° B5-5* 331° B5-6*		331° B5-11*	241° B5-12* 331° B5-13*	241° B5-14 310° B5-16 331° B5-15
26		No photographs available			
27		No photographs available			
28				241° B7-14* 331° B7-15*	241° B7-7* 331° B7-8*
29	0645: 241° B7-5 331° B7-6	200° B7-2 241° B7-3			
30		0945: 60° B8-12 241° B8-14 331° B8-13	241° B8-10* 331° B8-9	241° B8-8* 331° B8-7*	241° B8-6 331° B8-5
31	0645: 241° B8-4* 331° B8-3*	241° B8-2* 331° B8-1*			

* Quality fair only.
** In requesting photographs listed above, be certain to refer to A Series.
*** The 3-hourly times given at the top of the columns apply except where other times are entered.

(Degrees show direction in which camera was pointed.)

HOUR:***	0600	0900	1200	1500	1800
DATE					
18			61° K1-1 151° K1-2	61° K1-5 151° K1-6	61° K1-8 151° K1-11
19	0630: 61° K1-12 151° K1-13	61° K1-17 151° K1-18			
20			1210: 61° K2-2 151° K2-3	1510: 61° K2-5 151° K2-4	1810: 61° K2-6
21		0910: 61° K2-8 151° K2-9	61° K2-10	61° K2-12* 151° K2-13	61° K2-14* 151° K2-15*
22	0640: 61° K2-16* 151° K2-17*	0900: 61° K3-9* 151° K3-8*			
23		40° K5-1* 151° K5-2	61° K5-3		
24		No photographs available			
25			61° K6-20* 151° K6-19*	61° K6-18* 151° K6-17*	61° K6-16* 151° K6-15*
26	0655: 61° K6-14 151° K6-13	61° K6-12 151° K6-11	61° K6-9* 151° K6-10*	61° K6-6 151° K6-5	61° K7-2*
27	0700: 61° K7-4* 151° K7-5		61° K7-6 151° K7-7	61° K7-8 151° K7-9*	151° K7-11
28	0650: 61° K7-12				61° K8-2 151° K8-1
29	0645: 61° K8-4 151° K8-3*	61° K8-6* 151° K8-5	61° K8-8 151° K8-7*	61° K8-10 151° K8-9	61° K8-12 151° K8-11
30	0700: 61° K8-14 151° K8-13	61° K8-16*	61° K9-11* 151° K9-10*	61° K9-9 151° K9-8	30° K9-5 61° K9-7 151° K9-6*
31	0645: 61° K9-4 151° K9-3	61° K9-2 151° K9-1*			

* Quality fair only.
** In requesting photographs listed above, be certain to refer to A Series.
*** The 3-hourly times given at the top of the columns apply except where other times are entered.

PLACE: BRUCE

INDEX NUMBERS FOR CLOUD PHOTOGRAPHS, SERIES B,
JANUARY 29 - FEBRUARY 8, 1958**
(Degrees show direction in which camera was pointed.)

TABLE E

HOUR:*** DATE	0900	1200	1500	1800
29		241° B2-1 331° B2-3	241° B2-4 331° B2-5	241° B2-6 331° B2-7
30	241° B2-8* 331° B2-9*	241° B2-10 331° B2-11	241° B2-12 331° B2-13	241° B2-14 331° B2-15
31	241° B2-16* 331° B2-17	241° B2-18 331° B2-19	241° B2-20 331° B2-21	241° B2-22 331° B2-23
1	241° B2-24* 331° B2-25*	241° B2-26* 331° B2-27*	241° B2-28 331° B2-29	241° B2-30 331° B2-31
2		241° B3-1* 331° B3-2	241° B3-3 331° B3-4	250° B3-5 331° B3-6
3	280° B3-7* 331° B3-8	241° B3-9 331° B3-10	241° B3-11 331° B3-12	241° B3-13 331° B3-14
4	241° B3-15 331° B3-16	241° B3-18 331° B3-17	241° B3-20 331° B3-19*	241° B3-22 331° B3-21
5	241° B3-24 331° B3-23	241° B3-26 331° B3-25	241° B3-28* 331° B3-27*	241° B3-30 331° B3-29*
6	241° B4-1 331° B4-2*	241° B4-3* 331° B4-5	241° B4-6 331° B4-8	
7	0830: 241° B4-9 331° B4-10	241° B4-11	241° B4-13* 331° B4-14	331° B4-15*
8	200° B4-18* 241° B4-16 331° B4-17			

* Quality fair only.
** In requesting photographs listed above, be certain to refer to B Series.
*** The 3-hourly times given at the top of the columns apply except where other times are entered.

PLACE: KEITH — INDEX NUMBERS FOR CLOUD PHOTOGRAPHS, SERIES B, JANUARY 25 - FEBRUARY 8, 1958** — TABLE F

(Degrees show direction in which camera was pointed.)

HOUR: DATE	0900	1200	1500	1800
25			151° K1-1	61° K1-2* 151° K1-3*
26	61° K1-4 151° K1-5	61° K1-6 151° K1-7	61° K1-8 151° K1-9	61° K1-10* 151° K1-11*
27		61° K1-15 151° K1-16*	61° K1-17 151° K1-18	61° K1-19 151° K1-20
28	61° K1-26* 151° K1-28	61° K1-29 151° K1-30	61° K1-31 151° K1-32	
29	70° K2-28 190° K2-27	50° K2-26 140° K2-25	140° K2-24	50° K2-23 140° K2-22
30	50° K2-21 140° K2-20	50° K2-19 140° K2-18	50° K2-17 140° K2-16*	50° K2-15 140° K2-14
31	50° K2-13 140° K2-12	70° K2-10 160° K2-11	70° K2-8 160° K2-9	70° K2-6 160° K2-7
1	40° K2-5	70° K2-4 160° K2-3		
2	70° K2-2 160° K2-1	50° K3-33 140° K3-32	140° K3-31*	50° K3-30 140° K3-29
3	50° K3-28 140° K3-27	50° K3-26 140° K3-25	50° K3-24* 140° K3-23*	50° K3-22 140° K3-21
4	50° K3-20 140° K3-19	50° K3-17 140° K3-18		50° K3-15* 140° K3-16*
5			50° K3-13 140° K3-14	
6	50° K3-2 110° K3-1 140° K3-3	50° K4-1 140° K4-2		
7		50° K4-3 140° K4-4	50° K4-5 140° K4-6	50° K4-7 140° K4-8
8	50° K4-9 170° K4-10			

* Quality fair only.

** In requesting photographs listed above, be certain to refer to B Series.

APPENDIX III.

BIBLIOGRAPHY

NOTE: The following bibliography is not intended to be comprehensive. Rather it lists works cited in this publication together with a few additional items that may prove particularly useful to those analyzing the data presented in this study.

A. For general information on geology, hydrography, and geography:

(1) Emery, Kenneth O., "Submarine Geology of Bikini Atoll," Bull. GSA, LIX, 855-60, 1948.

(2) Emery, Kenneth O., J. I. Tracey, Jr., and H. S. Ladd, "Geology of Bikini and Nearby Atolls," Geol. Surv. Prof. Paper 260-A, Washington: GPO, 1954.

(3) Gordon, Jr., A. R., Digest of Oceanographic Data for the Marshall Islands Area, U. S. Navy Hydrographic Office (duplicated), March, 1956.

(4) U. S. Department of Commerce, Coast and Geodetic Survey, Tide Tables 1958, "Central and Western Pacific Ocean and Indian Ocean." Washington: GPO.

(5) U. S. Navy Hydrographic Office, Sailing Directions for The Pacific Islands, I (H.O. Pub. No. 165A), Washington: GPO, 1952.

B. For meteorological data and discussions of the weather and climate of the Marshall Islands area:

(1) Reports by Joint Task Force Meteorological Center:

(a) JTFMC TP-1 Meteorological Report on Operation REDWING
Volume 1, Eniwetok
15 Nov 1956

(b) JTFMC TP-5 A Study of the 30,000 Foot Wind Field over the West Central Pacific
20 Dec 1957

(c) JTFMC TP-8 Meteorological Report on Operation HARDTACK
Volumes 1 - 6
March-July 1958

(d) JTFMC TP-15 A Study of the Mean Vertical Wind Structure over the Eniwetok Proving Ground Area
8 May 1959

NOTE: There are several other JTFMC reports that provide marginal information that may be of interest. For a list of these and of reports issued since February 1, 1960, inquiry may be made to: JTF-7 Meteorological Center, c/o Fleet Weather Central, FPO 128, San Francisco, California.

(2) U. S. Weather Bureau, Climatological Data, Hawaii and Climatological Data, Pacific. Prior to 1956, daily rainfall and temperature reports for stations in the Marshall Islands appeared in CD, Hawaii; thereafter they have appeared in CD, Pacific.

(3) U. S. Weather Bureau, Local Climatological Data, Majuro. This provides fairly detailed climatologic data in monthly and annual summary form.

(4) Central Meteorological Observatory, Climatic Records of Japan and the Far East Area. Tokyo: CMO, 1954. This provides mean monthly data for the period of Japanese occupancy of the Marshall Islands.

(5) Mitteilungen von Forschungsreisenden und Gelehrten aus den Deutschen Schutzgebieten, various volumes, 1906-1914. Gives daily rainfall values for stations in Micronesia.

(6) Schott, Gerhard, "Klimakunde der Südsee-Inseln," Handbuch der Klimatologie, IV, Part T, Berlin, 1938.

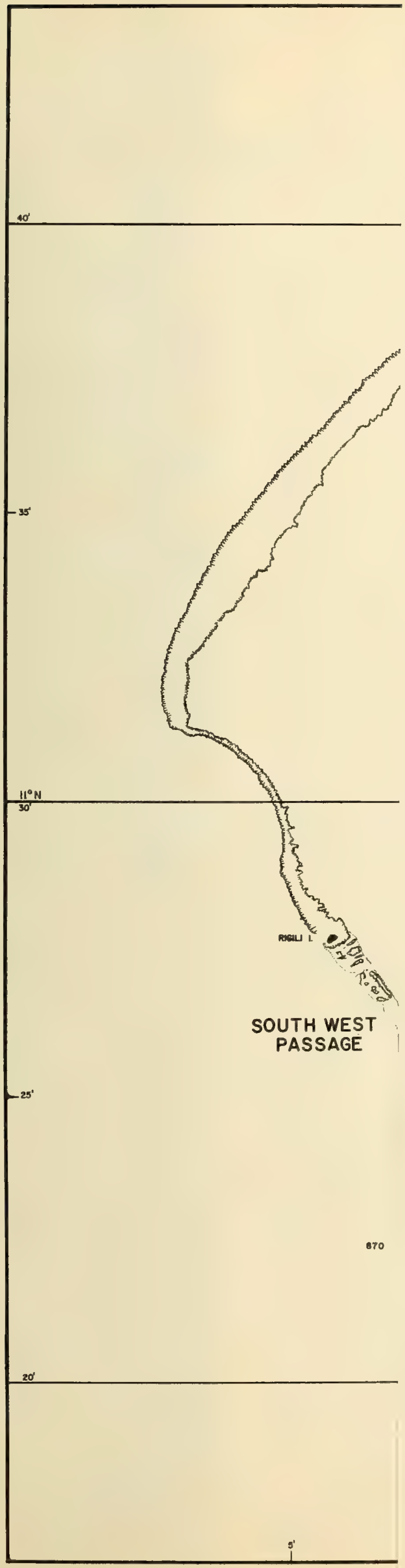
(7) Tüllman, Hubert, Die Niederschlagsverhältnisse der Südsee-Inseln: Archiv der Deutschen Seewarte, LVI, nr. 5. Hamburg.

C. The references cited above (especially the first three items) provide data that can be used to compile frequency distributions for meteorological variables in the Marshall Islands area. Types of distributions common in meteorology are discussed in the following:

(1) Brooks, C. E. P. and N. Carruthers, Handbook of Statistical Methods in Meteorology, M. O. 538. London, 1953.

(2) Panofsky, Hans A. and Glenn W. Brier, Some Applications of Statistics to Meteorology, Penn. State Univ., 1958.

FIGURES AND PLATES


40'
35'
11°N
30'
RIGILI I.
SOUTH WEST
PASSAGE
25'
870
20'
5'

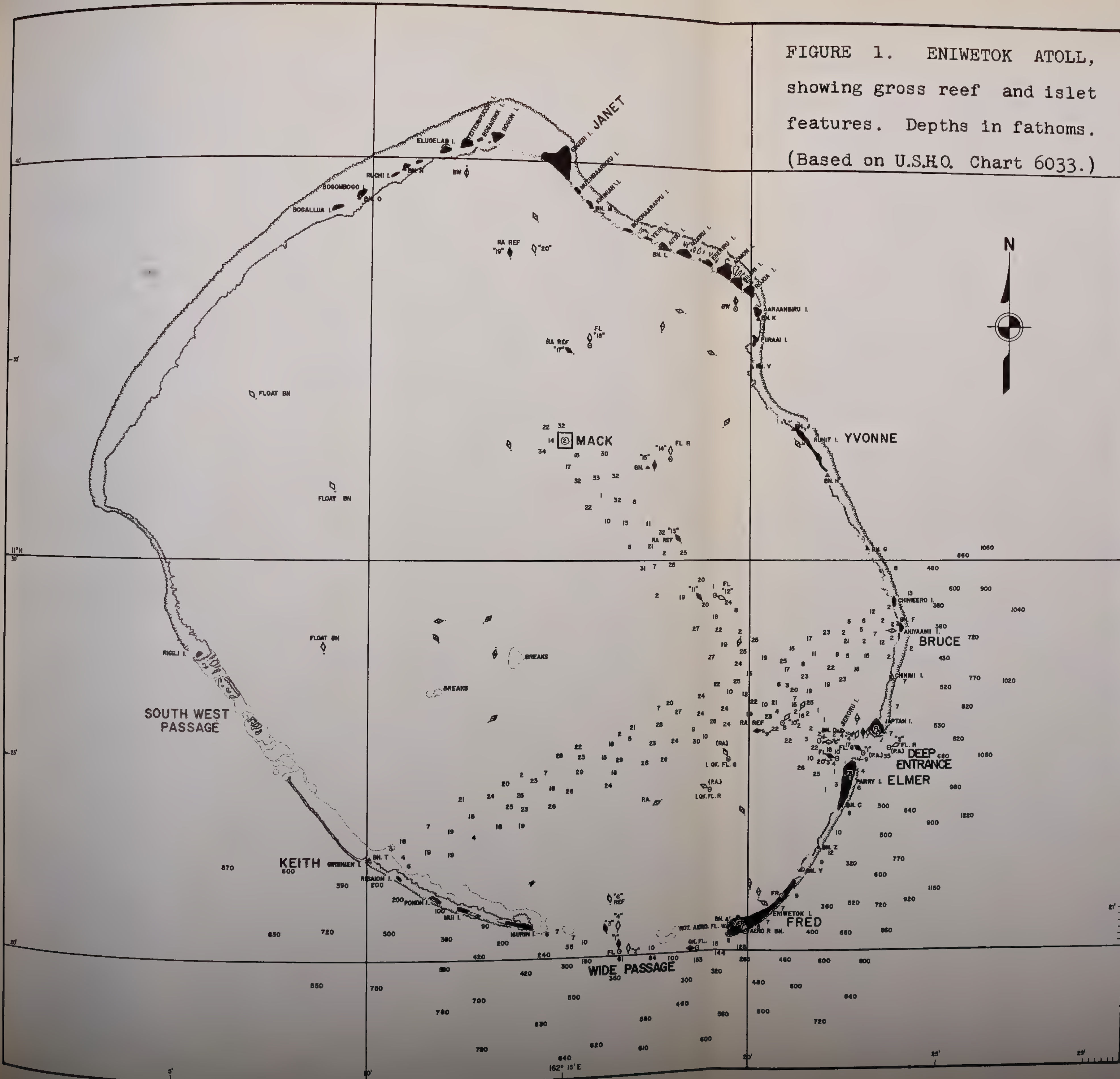


FIGURE 1. ENIWETOK ATOLL, showing gross reef and islet features. Depths in fathoms. (Based on U.S.H.O. Chart 6033.)

162° 05' E
10'
15'
20'
11° 40' N
JANET
11°40' N
N
20
24
28

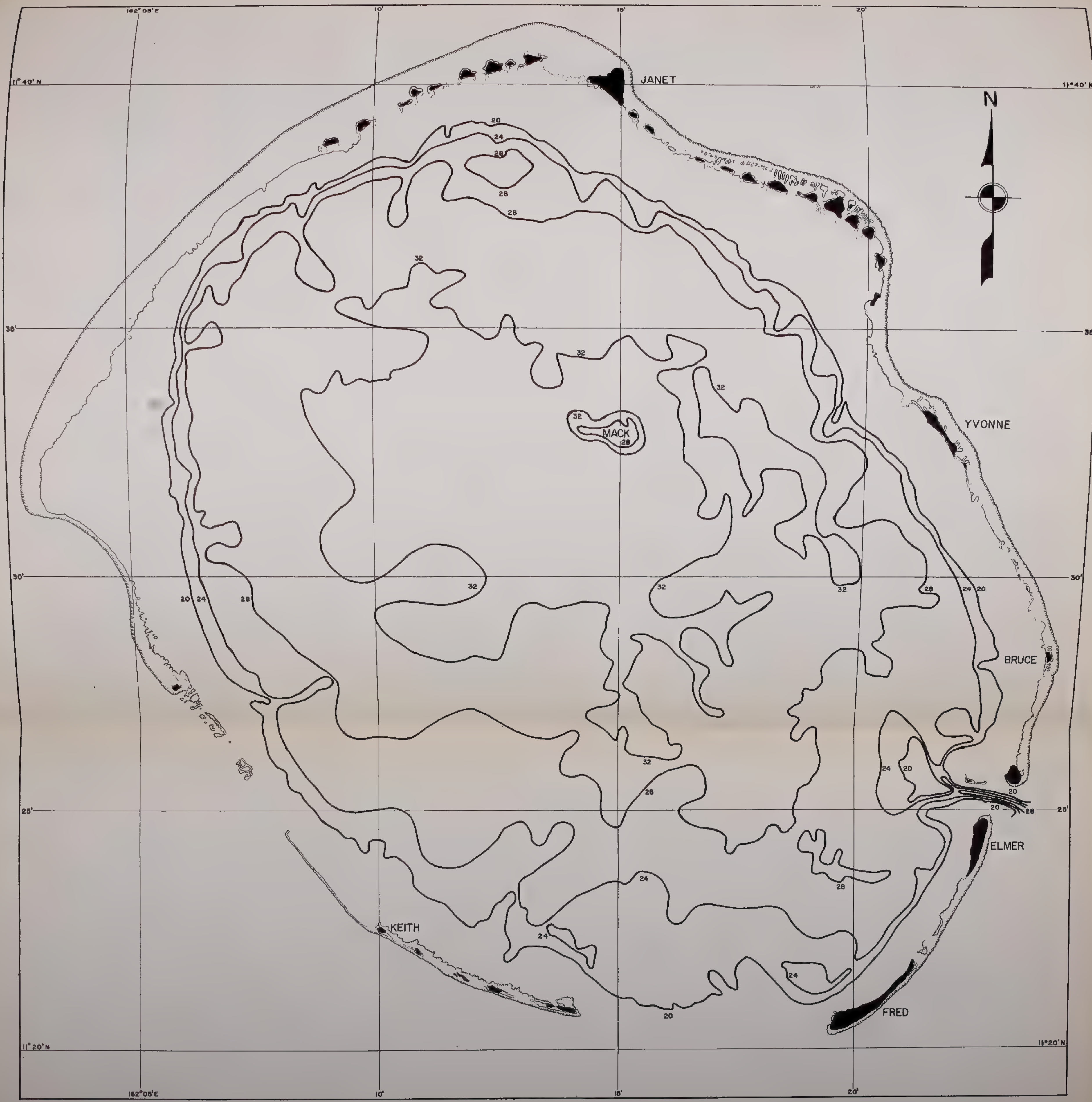


FIGURE 2. BATHYRITHMS, ENIWETOK LAGOON. Values are in fathoms below mean low tide. (Generalized bathyrithms, omitting coral heads and other details, adapted from Emery, Bull. GSA., LIX, 858.)

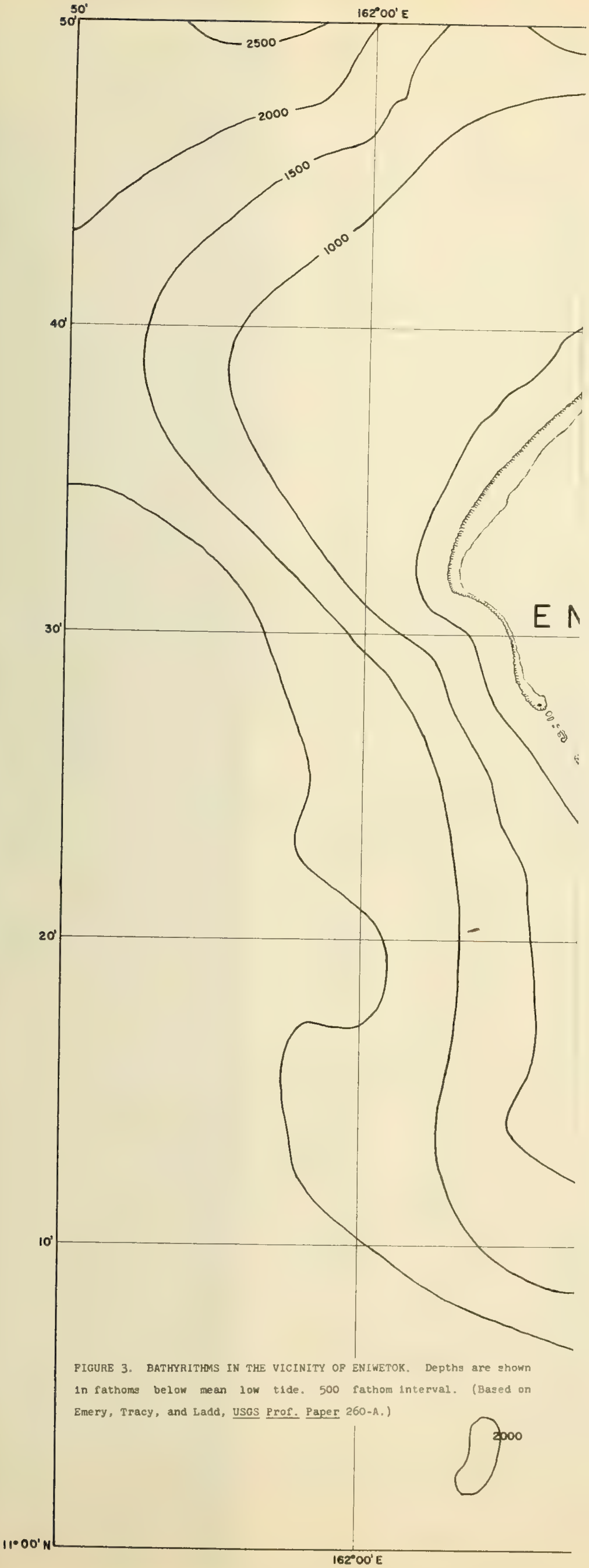


FIGURE 3. BATHYRITHMS IN THE VICINITY OF ENIWETOK. Depths are shown in fathoms below mean low tide. 500 fathom interval. (Based on Emery, Tracy, and Ladd, USGS Prof. Paper 260-A.)

FIGURE 3. BATHYRITHMS IN THE VICINITY OF ENIWETOK. Depths are shown in fathoms below mean low tide. 500 fathom interval. (Based on Emery, Tracy, and Ladd, USGS Prof. Paper 260-A.)

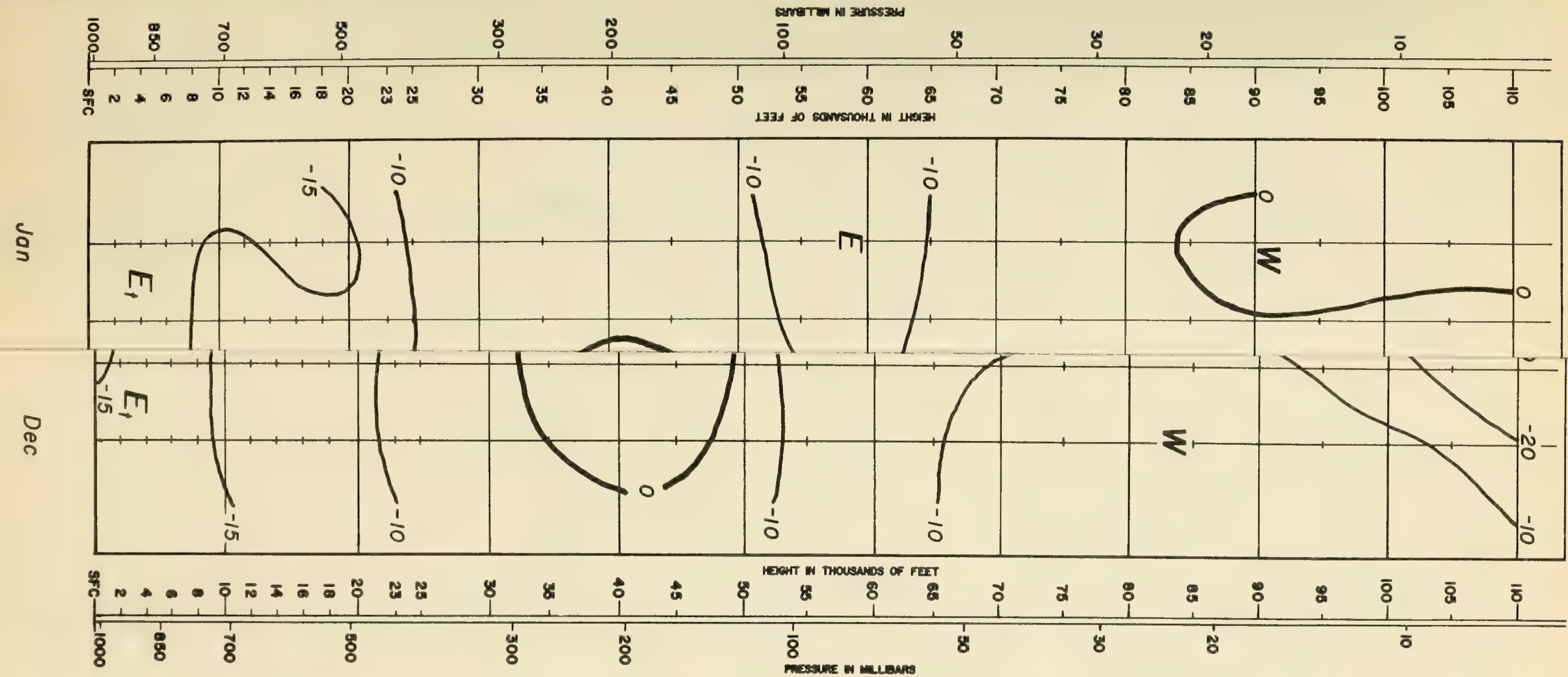


FIGURE 4. MEAN MONTHLY EAST-WEST WIND COMPONENTS, ENIWETOK, AS A FUNCTION OF ALTITUDE. Values in m.p.h., with west wind components positive. E_T: tradewind flow; W_U: upper westerly flow; E_E: equatorial easterlies; E_K: Krakatoa easterlies; W_B: Berson westerlies. (Based on twice-daily soundings, 1949 through 1958, and on additional soundings during test periods. From JTFMC TP-20.)

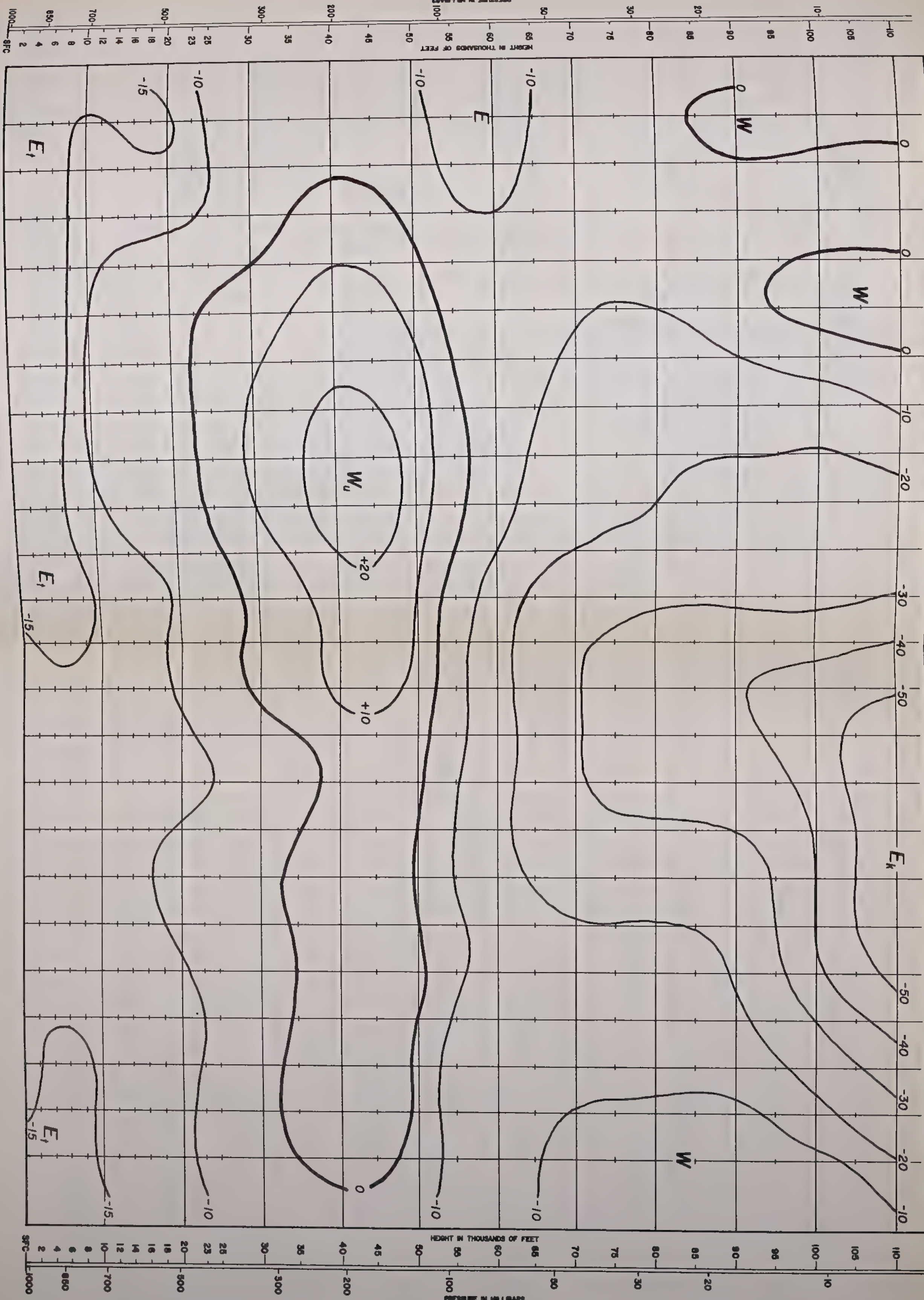


FIGURE 4. MEAN MONTHLY EAST-WEST WIND COMPONENTS, ENIWETOK, AS A FUNCTION OF ALTITUDE. Values in m.p.h., with west wind components positive. E_T: tradewind flow; W_U: upper westerly flow; E_E: equatorial easterlies; E_K: Krakatoa easterlies; W_B: Berson westerlies. (Based on twice-daily soundings, 1949 through 1958, and on additional soundings during test periods. From JTFMC TP-20.)

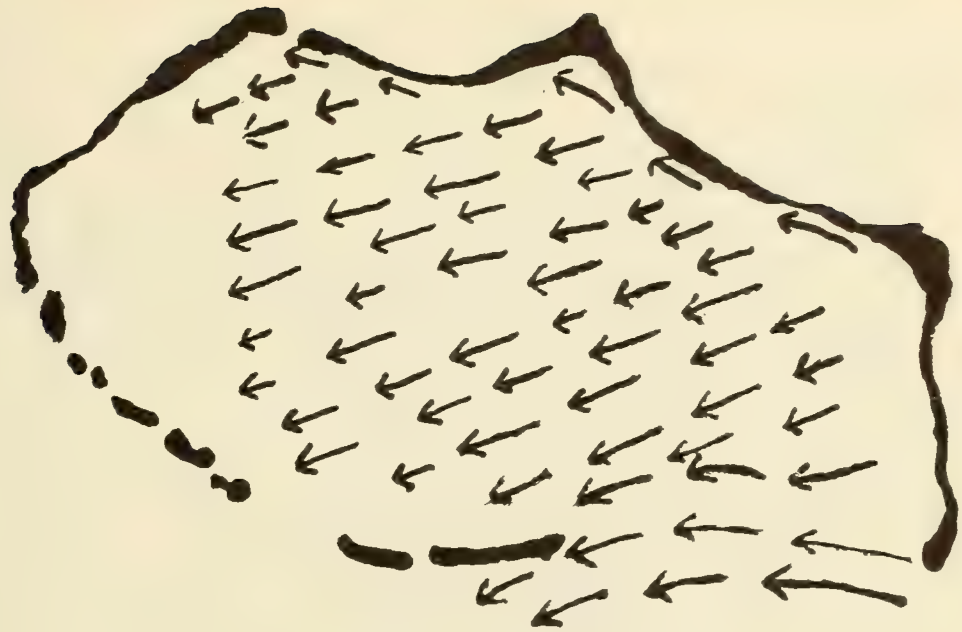


FIGURE 5-A. SURFACE WATER CURRENTS IN BIKINI LAGOON WITH AN ENE WIND. North is at the top of the map. Arrows show the flow pattern. (After A. R. Gordon, Jr.)

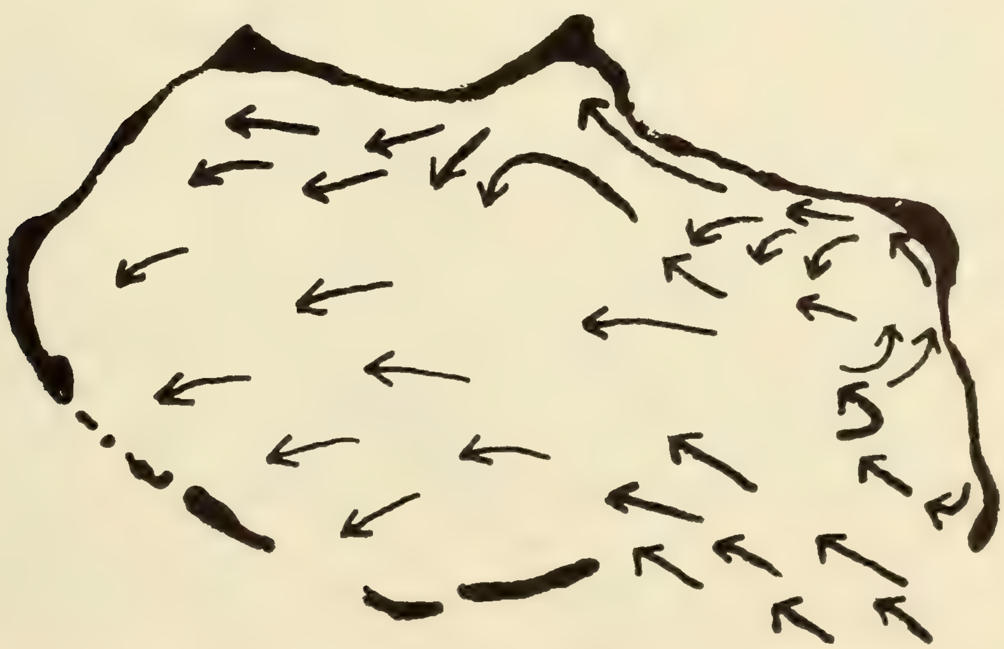


FIGURE 5-B. SURFACE WATER CURRENTS IN BIKINI LAGOON WITH A SE WIND. North is at the top of the map. Arrows show the flow pattern. (After A. R. Gordon, Jr.)

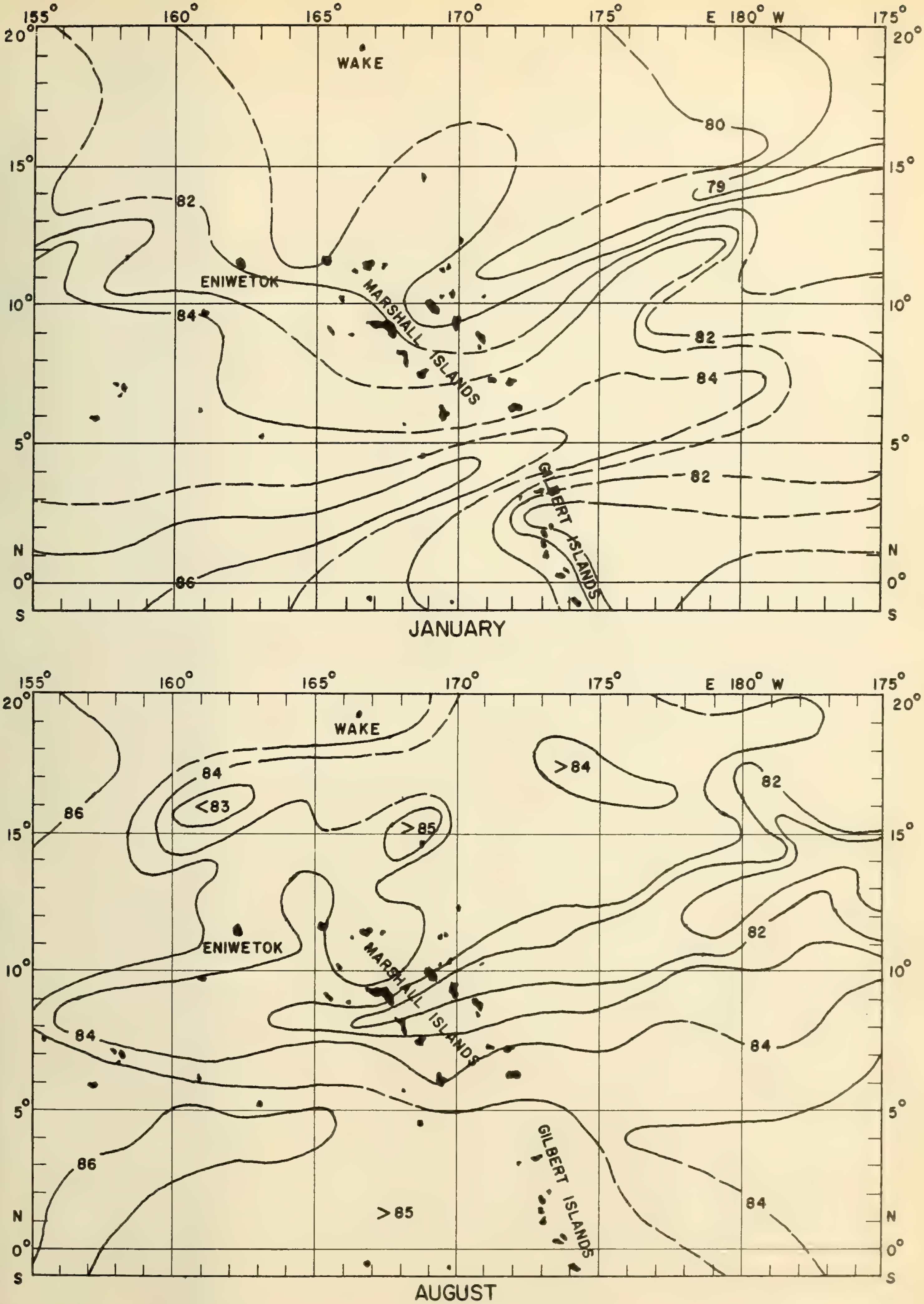
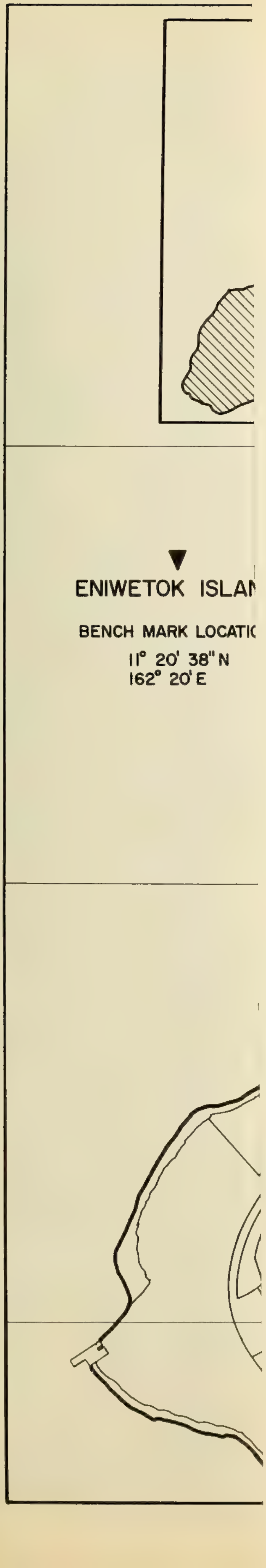


FIGURE 6. SURFACE WATER TEMPERATURES IN JANUARY AND AUGUST. Temperatures in °F. (From Emery, Tracy, and Ladd.)


ENIWETOK ISLAN
BENCH MARK LOCATIC
11° 20' 38" N
162° 20' E

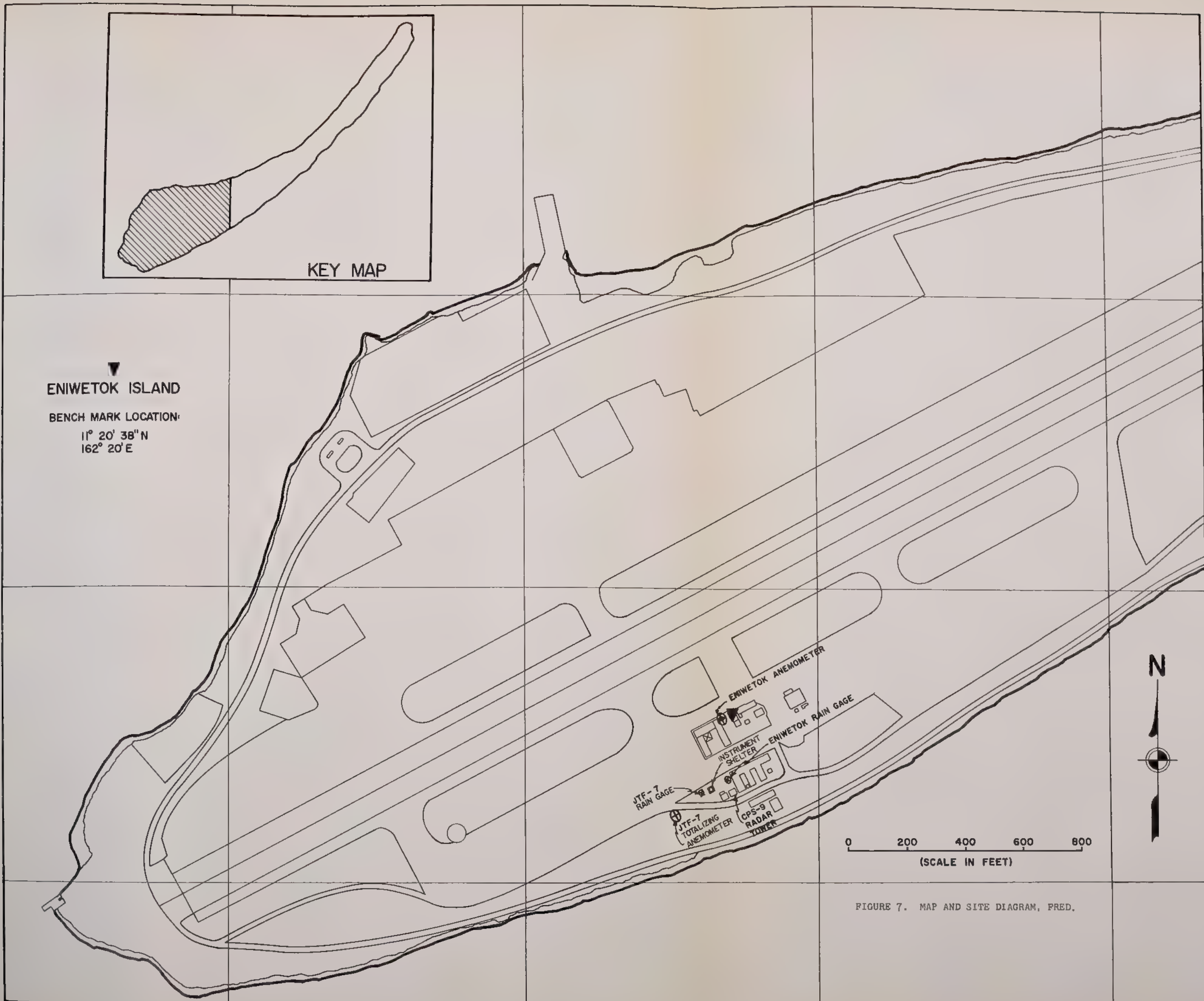


FIGURE 7. MAP AND SITE DIAGRAM, FRED.

FIGURE 8. MAP AND SITE DIAGRAM, ELMER.

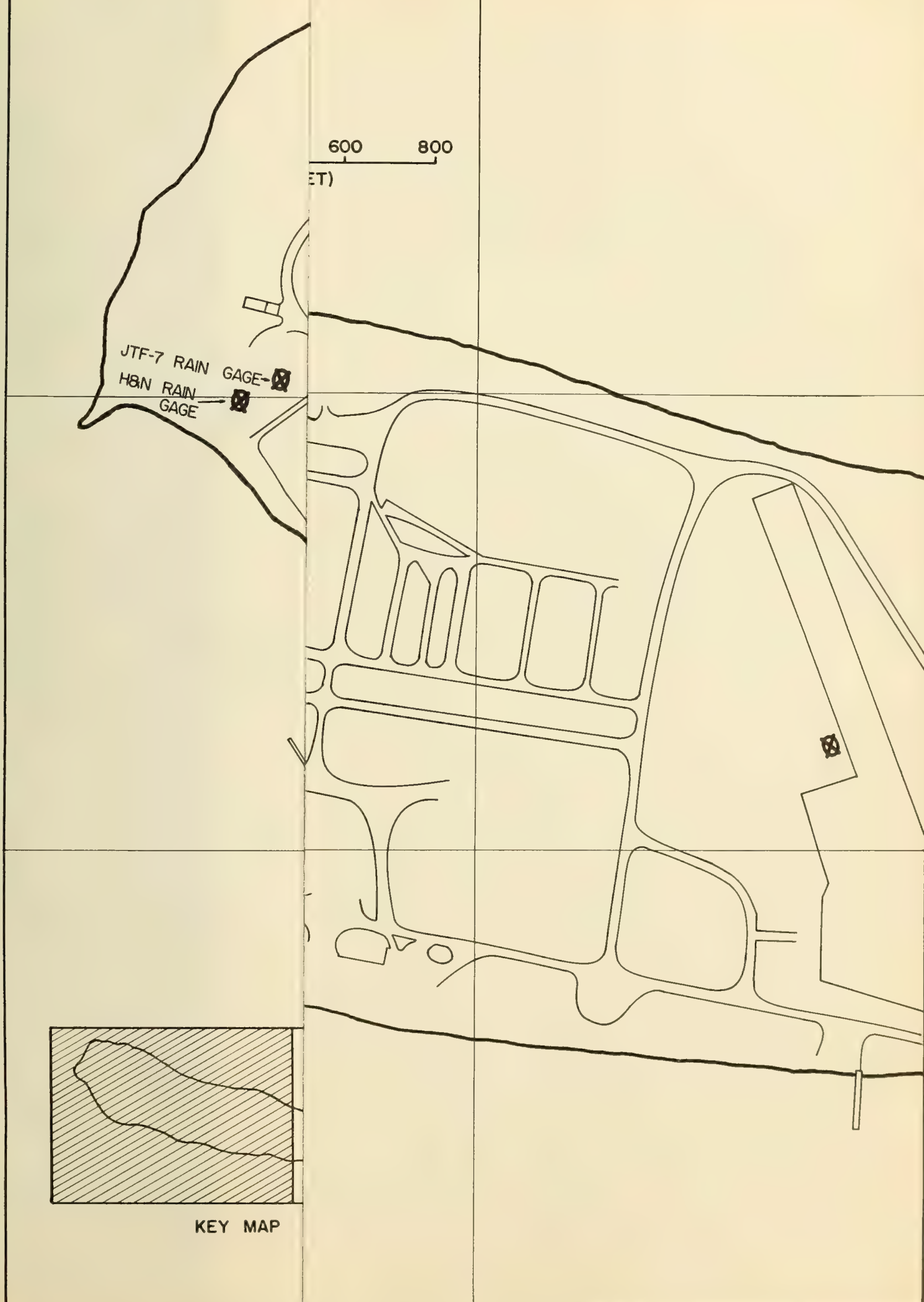
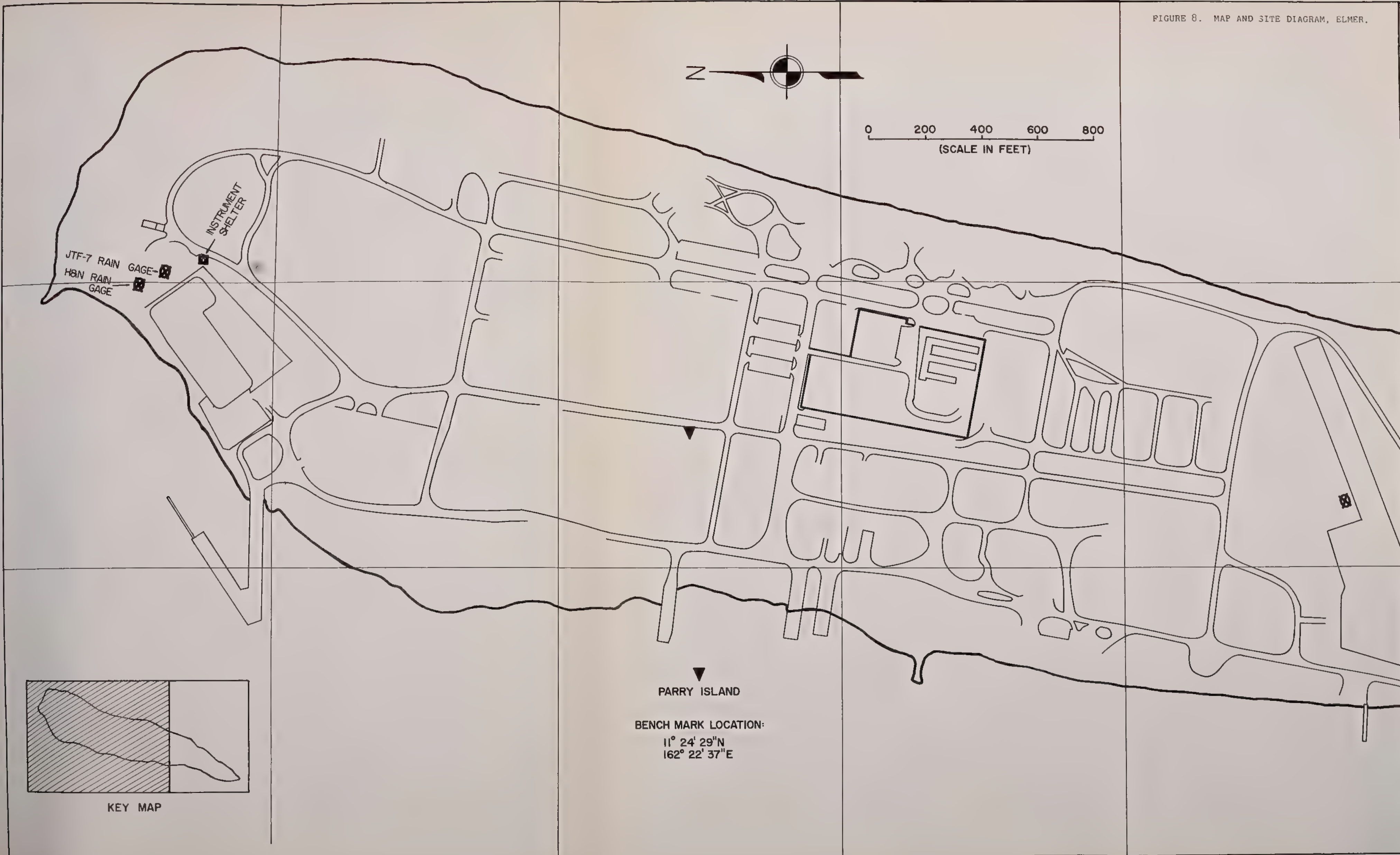
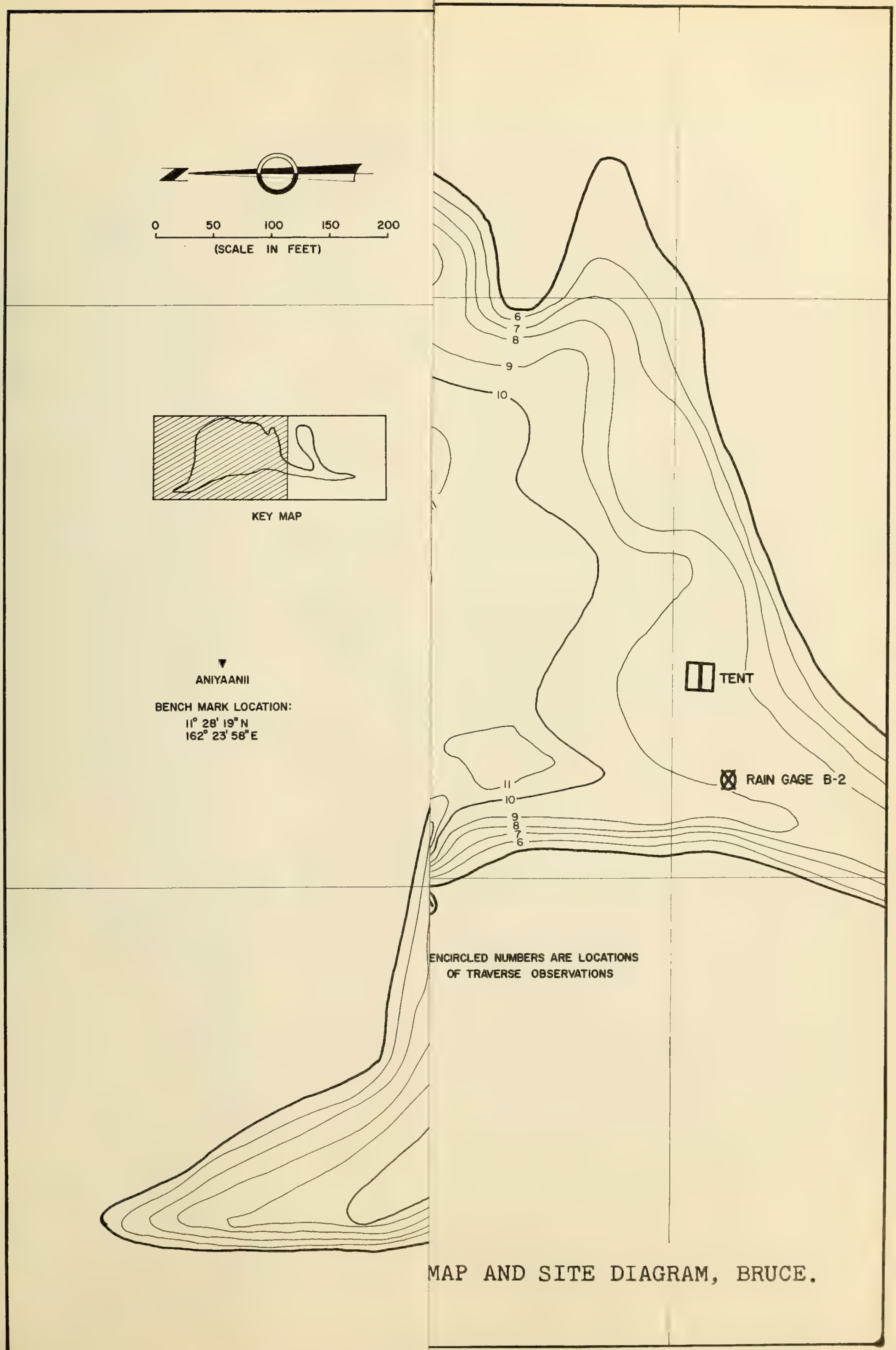


FIGURE 8. MAP AND SITE DIAGRAM, ELMER.





MAP AND SITE DIAGRAM, BRUCE.

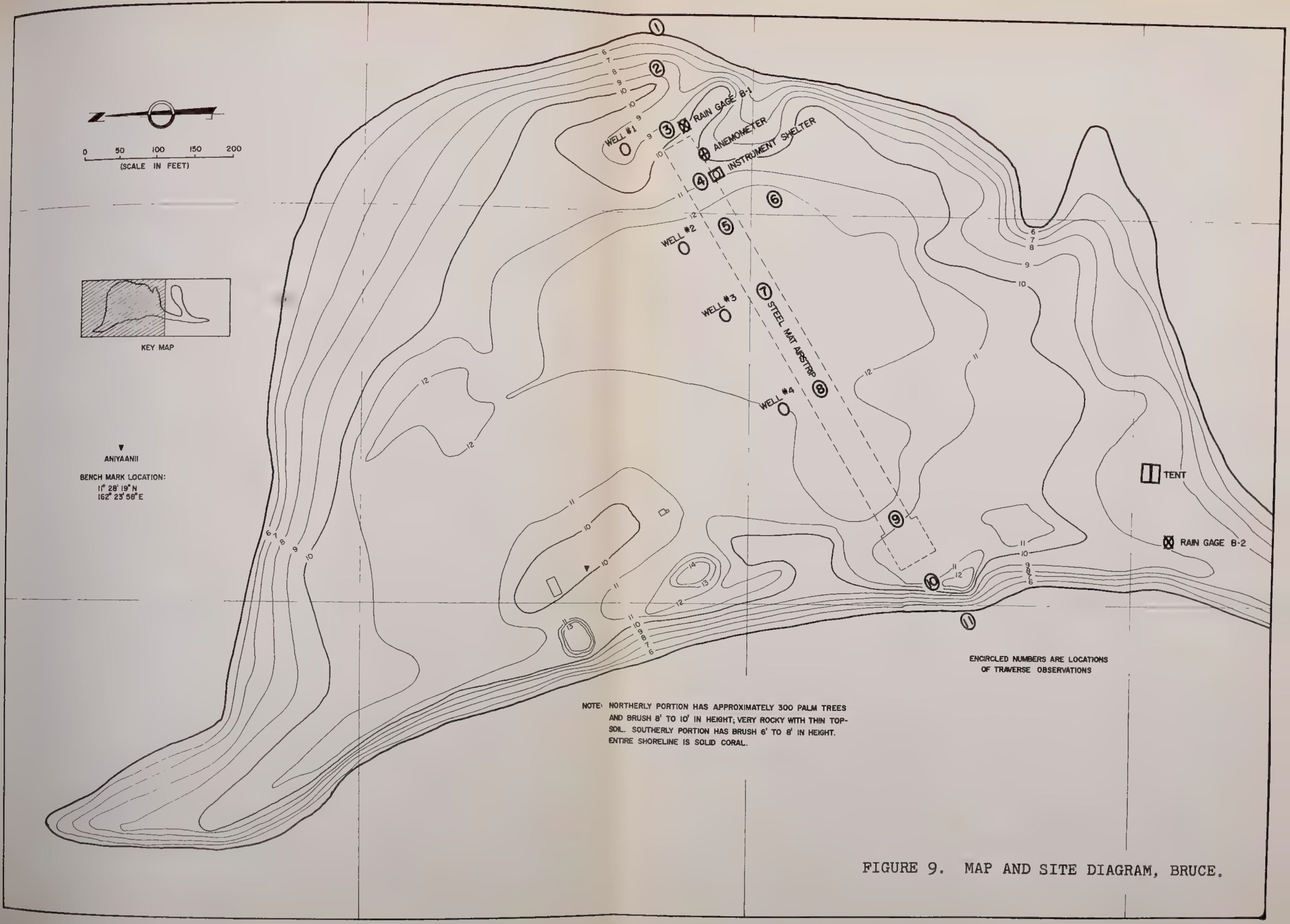


FIGURE 9. MAP AND SITE DIAGRAM, BRUCE.

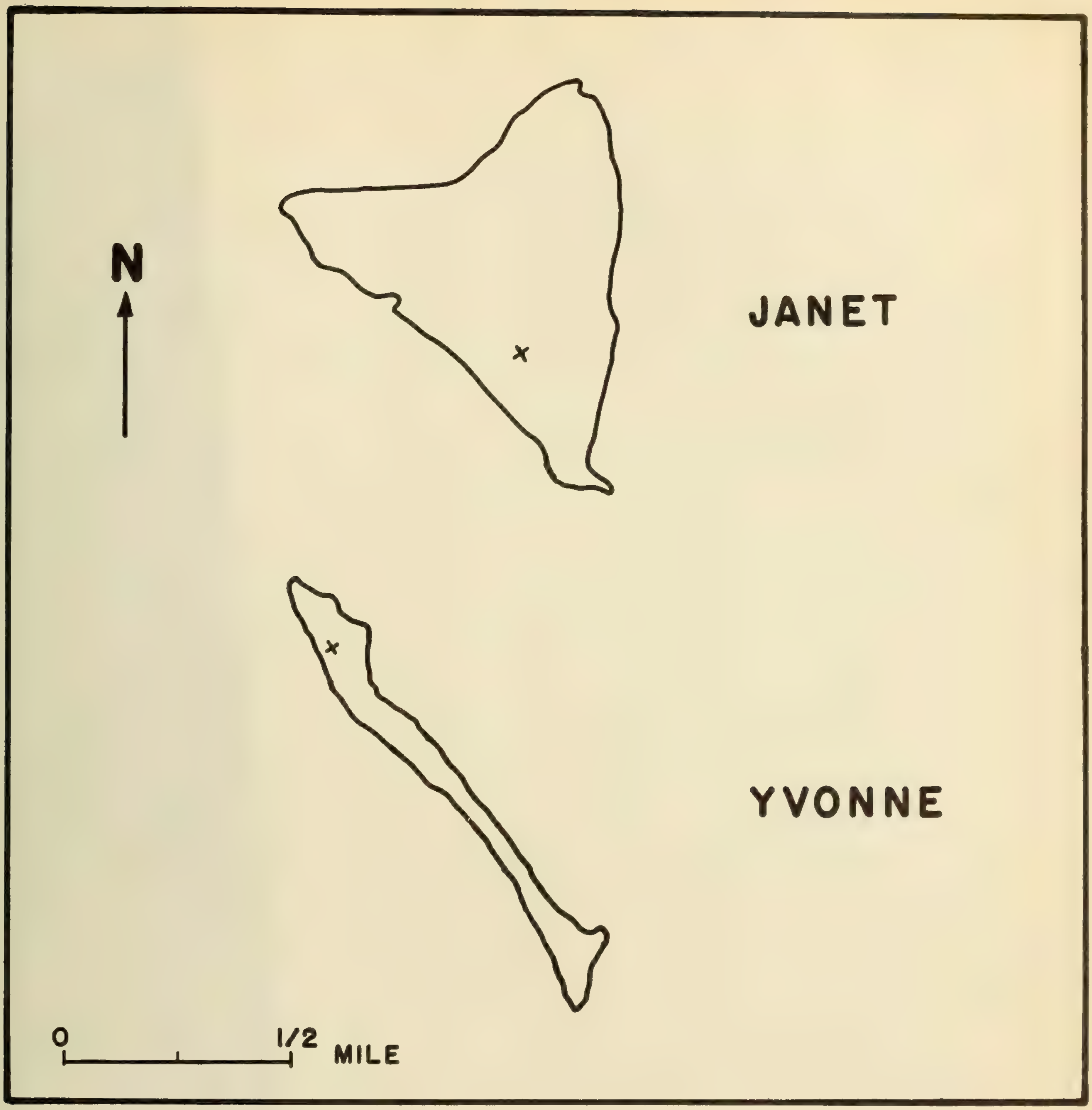


FIGURE 10. SKETCH MAPS OF JANET AND YVONNE ISLETS. Maps are approximate only. Scale correct within 15%. Raingage locations shown by "X". For positions of islets on the reef, see Figure 1.

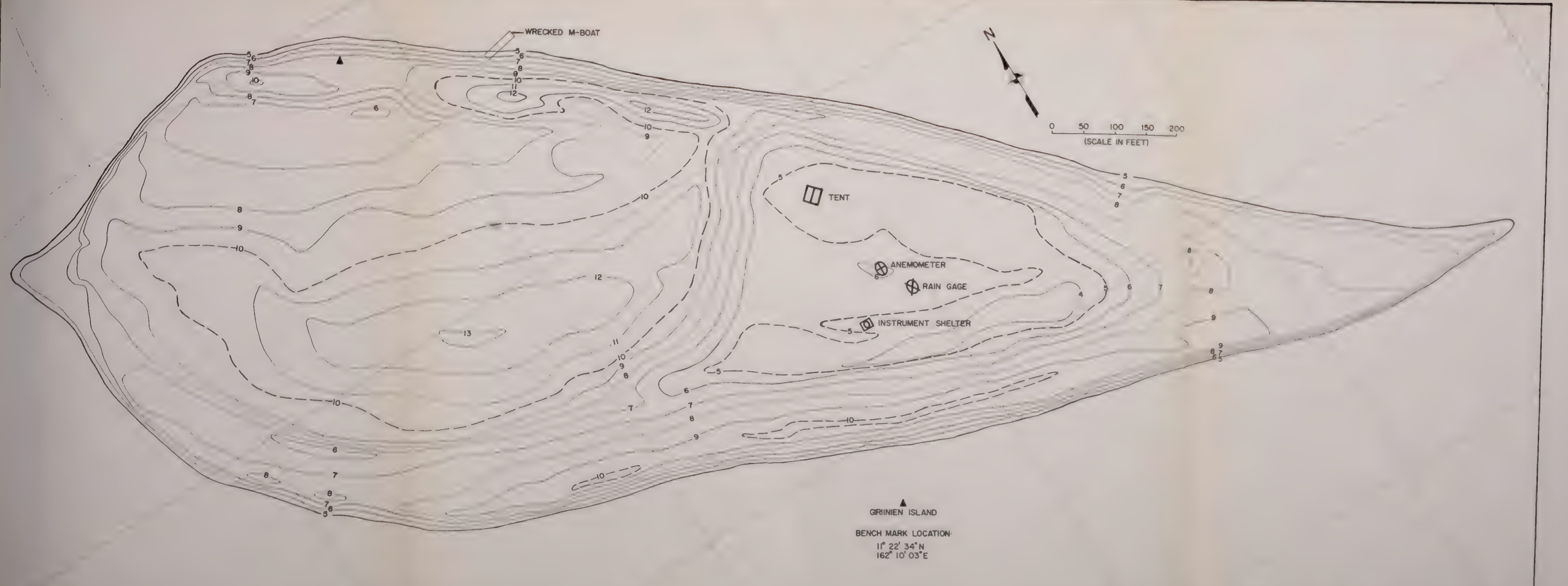


FIGURE 11. MAP AND SITE DIAGRAM, KEITH.

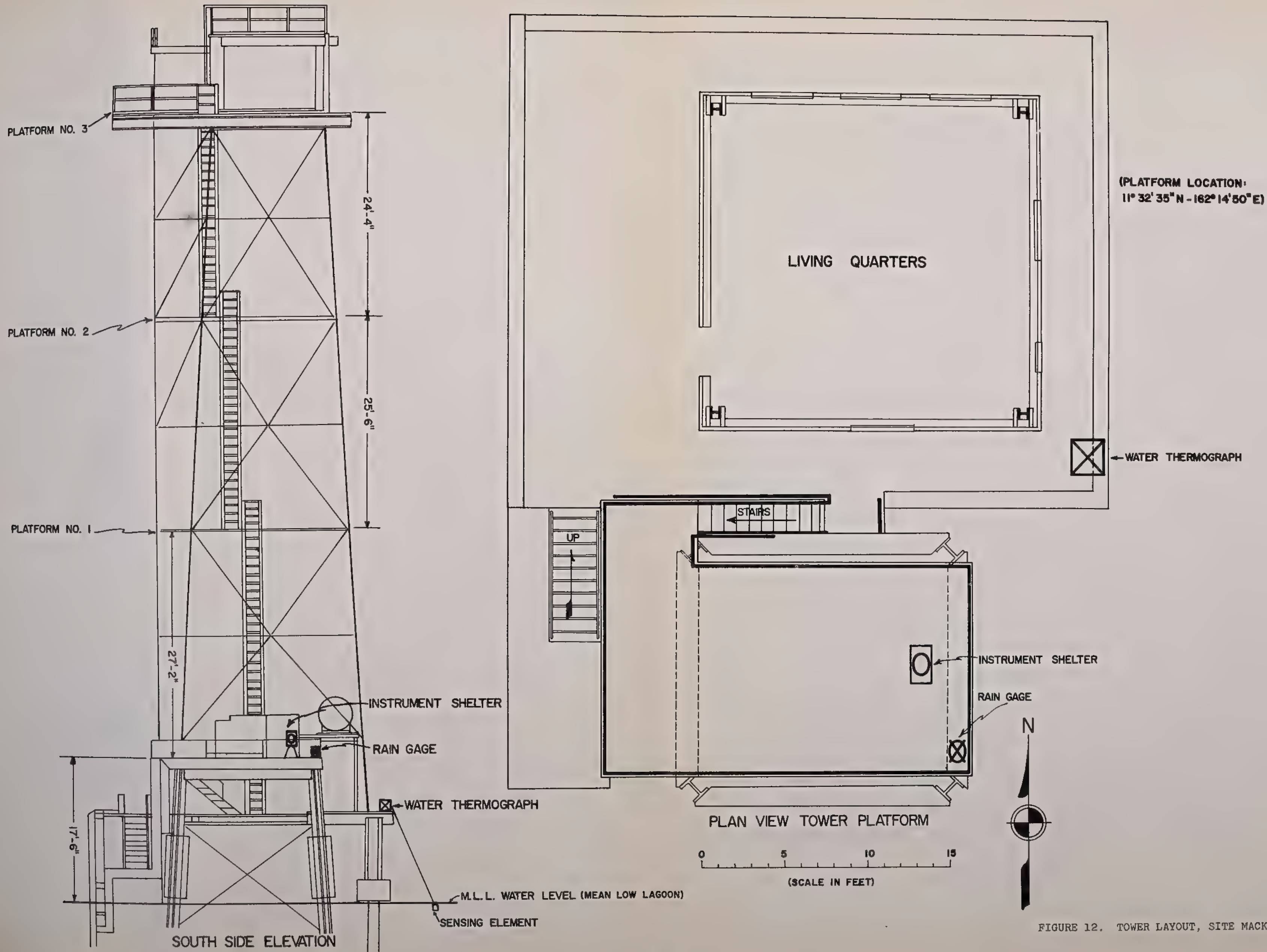
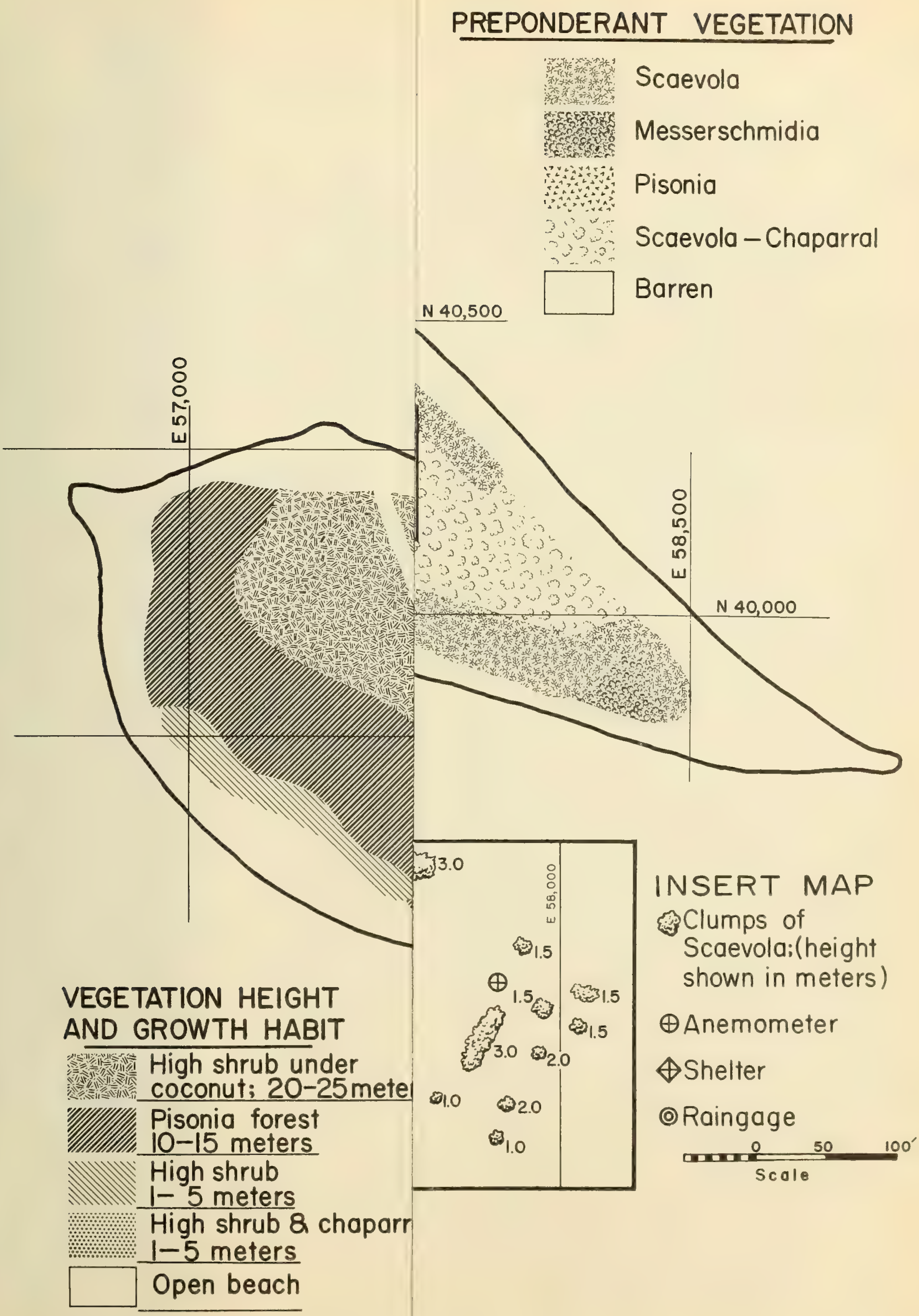


FIGURE 12. TOWER LAYOUT, SITE MACK.


PREPONDERANT VEGETATION
Scaevola
Messerschmidia
Pisonia
Scaevola – Chaparral
Barren
N 40,500
E 57,000
E 58,500
N 40,000
3.0
E 58,000
1.5
1.5
1.5
1.5
3.0
2.0
1.0
2.0
1.0
INSERT MAP
Clumps of Scaevola:(height shown in meters)
Anemometer
Shelter
Raingage
0
50
100′
Scale
VEGETATION HEIGHT AND GROWTH HABIT
High shrub under coconut; 20-25meter
Pisonia forest 10–15 meters
High shrub 1– 5 meters
High shrub & chaparr
1–5 meters
Open beach

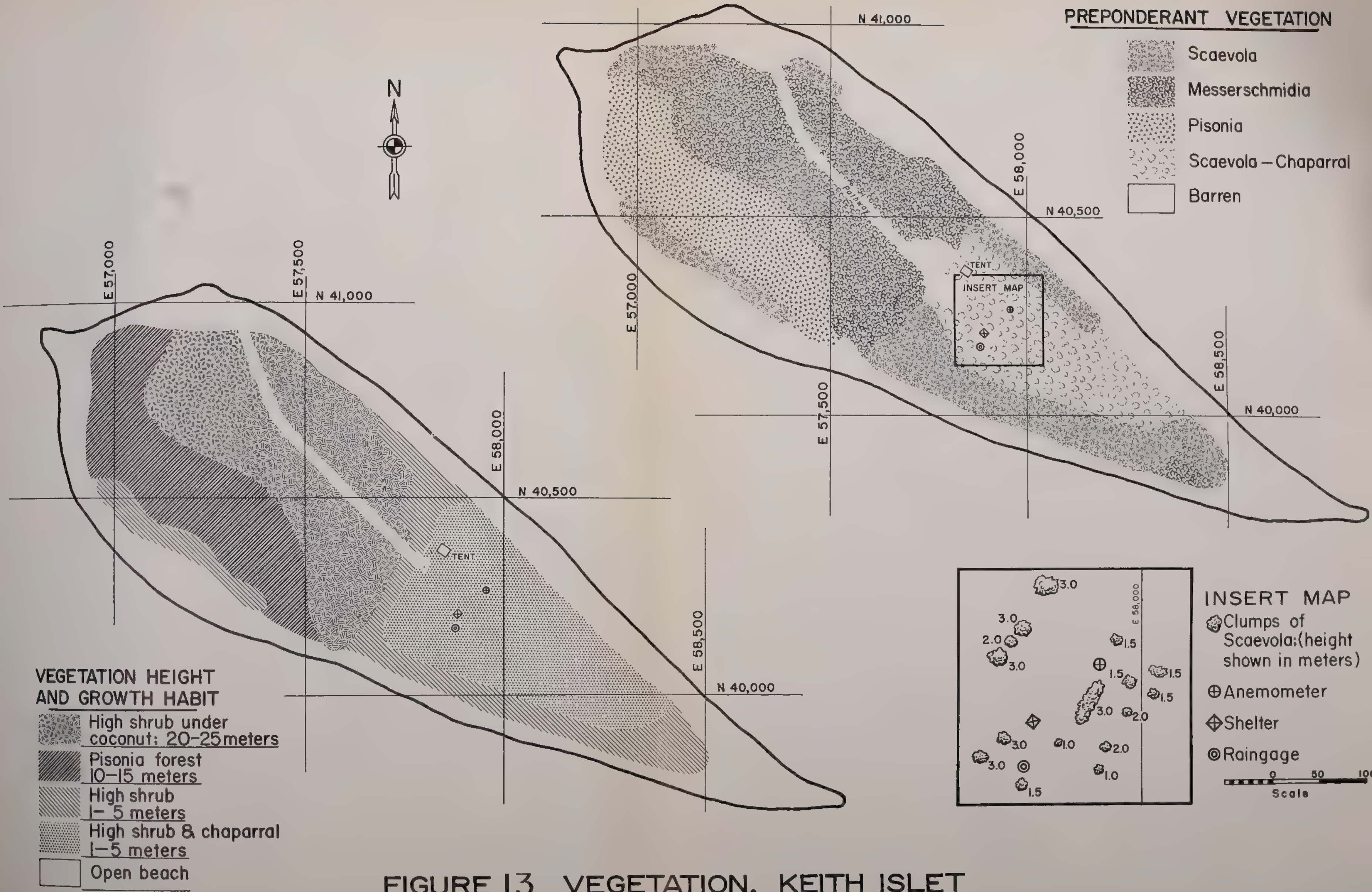


FIGURE 13 VEGETATION, KEITH ISLET

0 400′
Scale

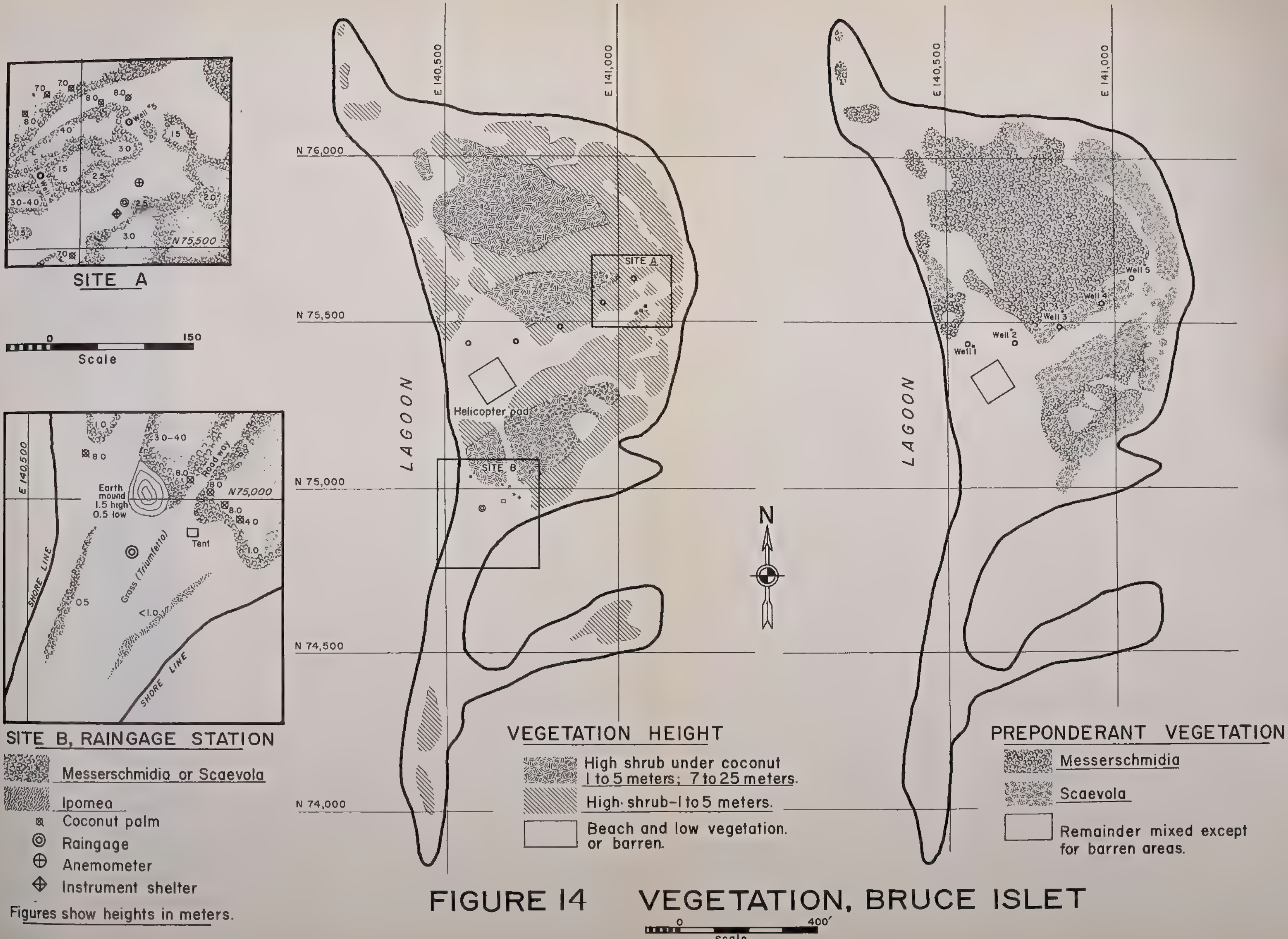


FIGURE 14 VEGETATION, BRUCE ISLET

PLATE I-A. WEATHER INSTRUMENTS, BRUCE Islet, ocean side location.

Above: Shelter, anemometer, and raingage, looking east (toward ocean).

Below: Same, looking west (down old runway toward lagoon).

PLATE I-B. RAINGAGE, BRUCE Islet, lagoon side location.

Above: Looking east (toward ocean). Below: Looking west (toward lagoon).

<u>Above</u>: Anemometer and shelter, looking SSW (toward ocean). Rain-gage is to right beyond shelter.

<u>Right</u>: Anemometer mast, showing barren nature of surrounding ground and looking SW.

PLATE II. WEATHER INSTRUMENTS, KEITH Islet.

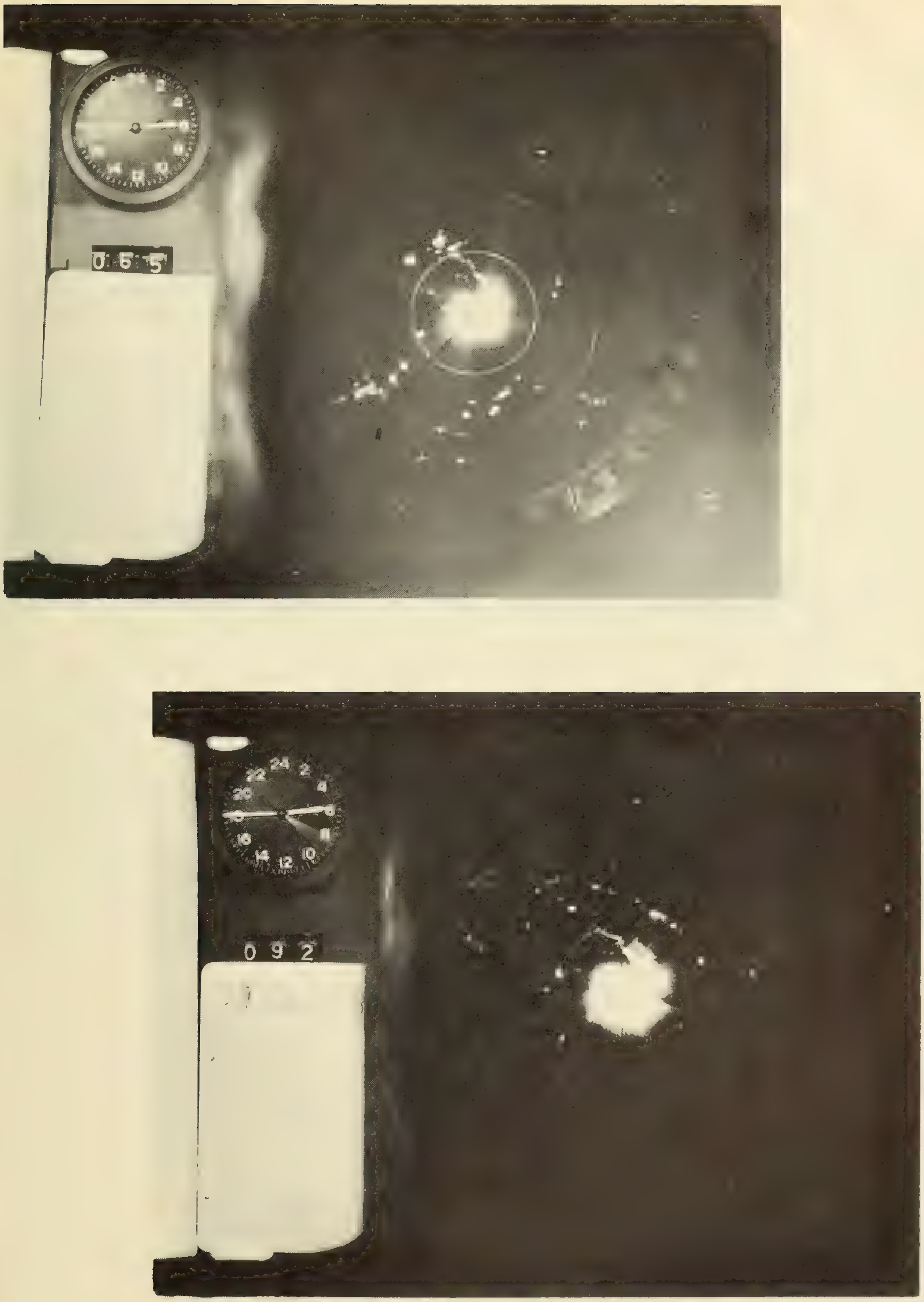


PLATE III. TYPICAL RADARSCOPE VIEWS.

Range: 75 miles. North is at the top of the scope.

PLATE IV. REPRESENTATIVE CLOUD PICTURES. The two shown were taken from KEITH Islet, January, 1958.

Nos. 72, 73, 74 October 15, 1960

ATOLL RESEARCH BULLETIN

72. *Report on Tarawa Atoll, Gilbert Islands*
by Edwin Doran, Jr.

73. *Some aspects of Agriculture on Tarawa Atoll, Gilbert Islands*
by R. R. Mason

74. *Birds of the Gilbert and Ellice Islands Colony*
by Peter Child

Issued by

THE PACIFIC SCIENCE BOARD

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ACKNOWLEDGMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past thirteen years.

The preparation and issuance of the Atoll Research Bulletin is assisted by funds from Contract N7onr-2300(12).

Bulletin No. 72, Report on Tarawa, was originally duplicated by the U. S. Navy for limited internal distribution. In order to make this information more widely available to those interested in Pacific Atolls the Navy has considerately made the report available for distribution as an Atoll Research Bulletin.

Correspondence concerning the Atoll Research Bulletin should be addressed to the above

c/o Pacific Science Board
National Research Council
2101 Constitution Avenue, N. W.
Washington 25, D. C., U.S.A.

ATOLL RESEARCH BULLETIN

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Report on Tarawa Atoll, Gilbert Islands

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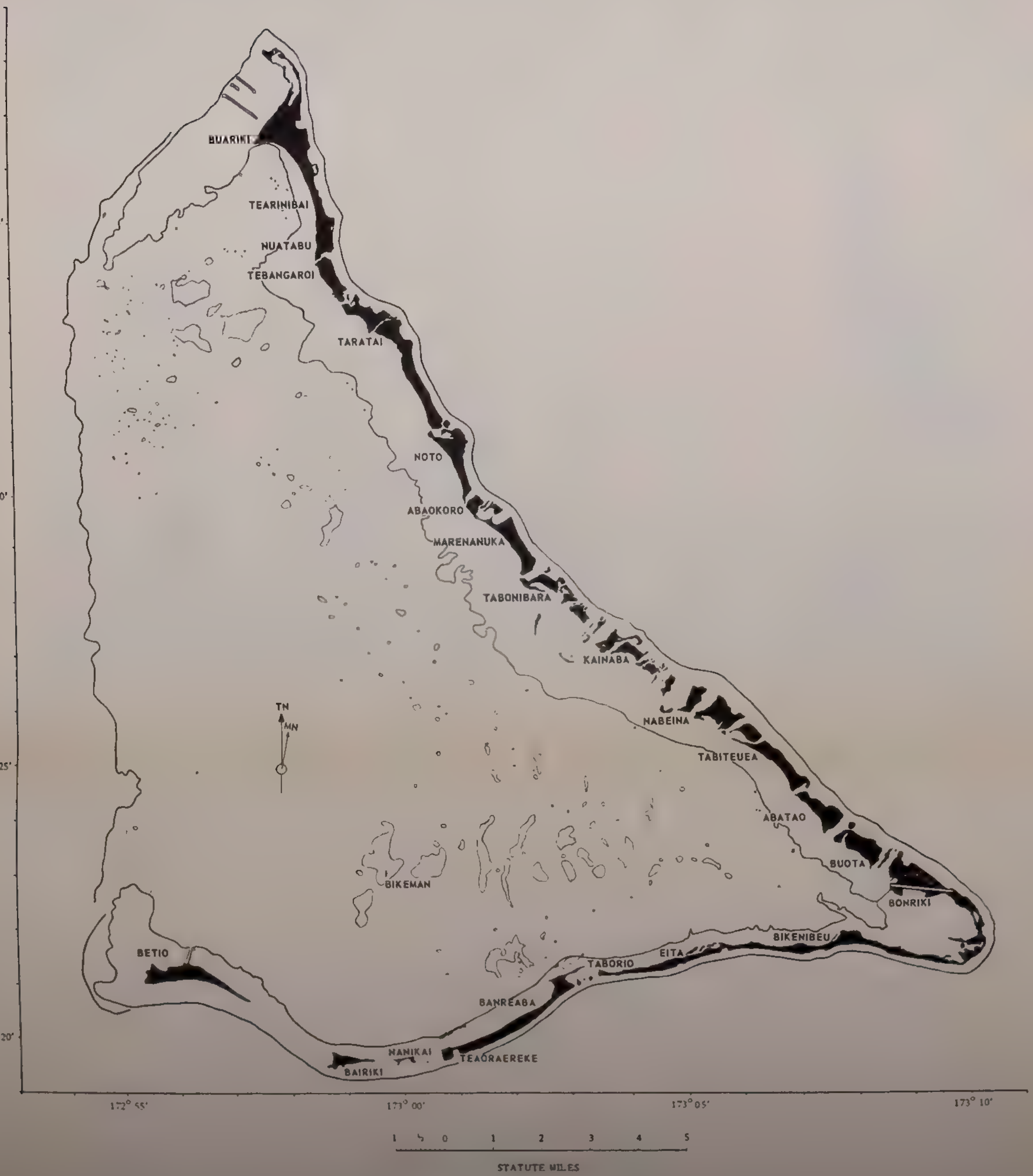
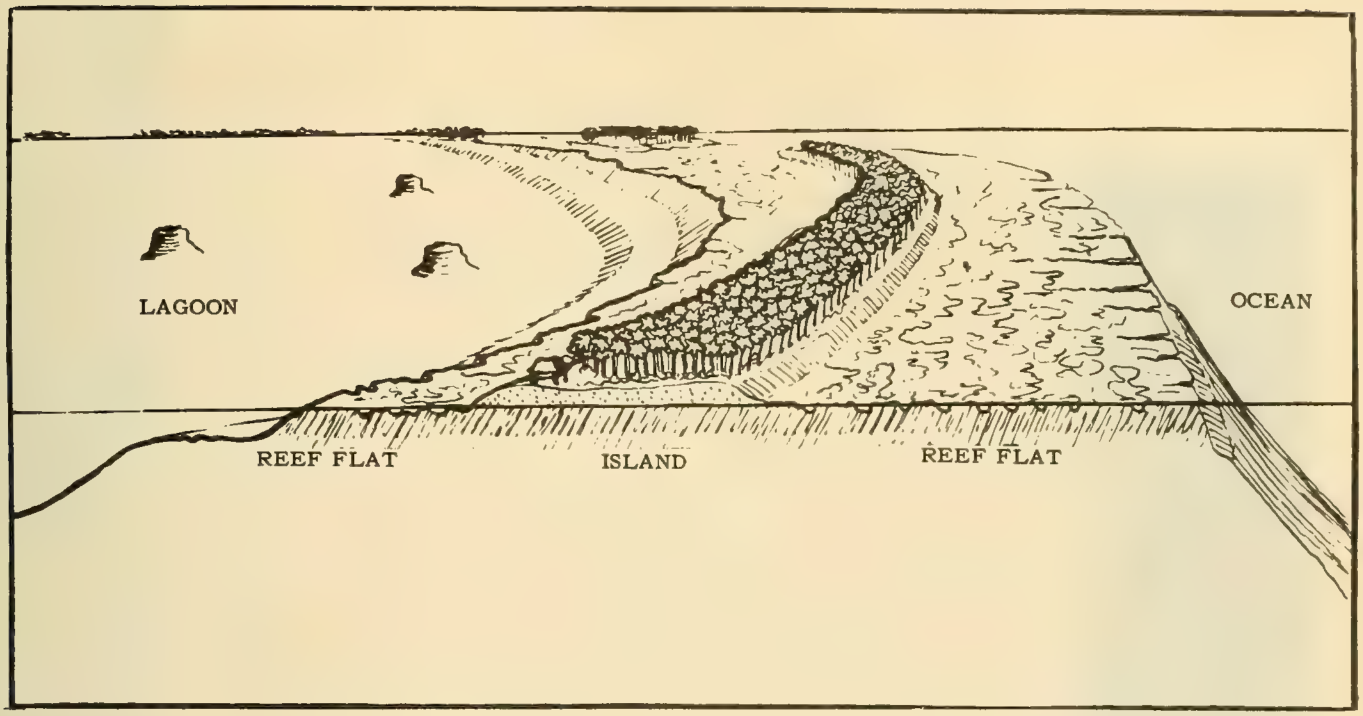


Figure 1. Map of Tarawa Atoll.



-- Taken from Atoll Research Bulletin No. 59.

Figure 2. Schematic Constitution of an Atoll.

around much of the atoll (figure 3). Bordering the land on both seaward and lagoon sides are continuous expanses of fringing reef, bare at low tide and covered with shallow water at high tide. These Tarawa reefs are often 400 to 700 yards wide on both the inner and outer sides of islands.

It should be noted that no type of rock other than limestone is exposed in the Gilbert Islands. The form of the rock may vary, however, from solid skeletons of corals cemented with various lime-secreting algae into a solid limestone platform, to sands and gravels created by erosion, comminution, and subsequent deposition of fragments of corals and algae.

Although hills are completely absent and maximum elevations above sea level are on the order of 20 feet, there is nevertheless a certain irregularity in atoll terrain (figure 4). Near the water on the ocean side, there typically is found a beach ridge, with steeper slopes toward the sea and more gentle declivities inland toward the center of the island. Elevations in the interior may be as little as 2 to 5 feet, from which a gentle slope again rises to a somewhat higher crest in the vicinity of the lagoon beach. Gradients on the lagoon side are gentle, and the slight elevation above the interior of the island is hardly noticeable. Even the slope down to the edge of the water, the inner side of the lagoon fringing reef, is quite gentle.

On the ocean sides of islands, beaches are moderately steep and are formed of fairly coarse gravel-sized fragments of corals thrown up by the waves. On the lagoon sides, beach materials are finer grained, often approaching a powdery sand in consistency. Where little wave action is found, as in Temaiku Bight within the southeast angle of the atoll, the sediments that accumulate are fine grained and form extensive flats of light-colored mud.

The reef flats that fringe the land on both ocean and lagoon sides of islets are formed by dead corals with thin layers of mud or debris spread over them and occasional boulders scattered about as relicts of storm waves in the past. Bare at low tide and often with a somewhat unpleasant

Figure 3. Aerial View of Islet Between Bairiki and Nanikai in Tarawa Atoll at Low Tide When Passage Between Islands Is Traversable by Motor Vehicles.

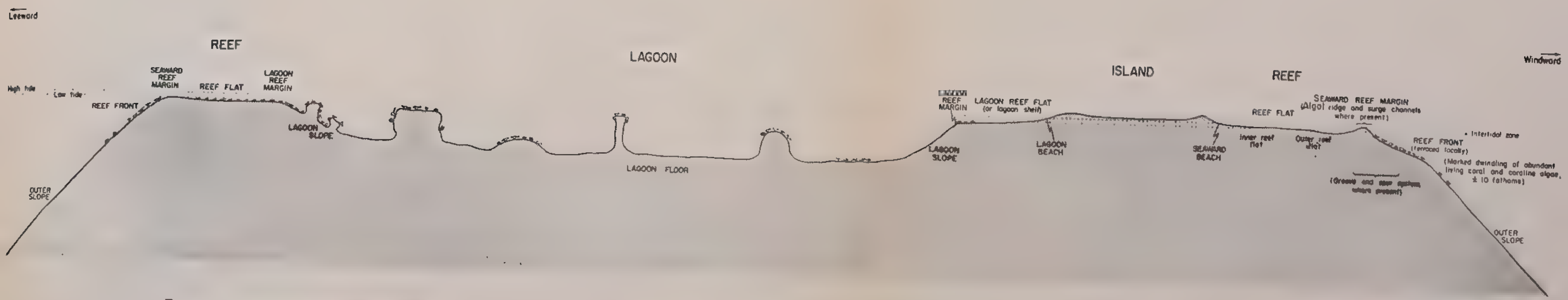


Figure 4. Typical Conspicuous Features of an Atoll and Its Peripheral Reef.

– – Taken from Atoll Research Bulletin No. 46.

smell from the decomposition of countless tiny organisms stranded by the low water, the reef flats are covered with several feet of water at high tide. Small wavelets ripple across them and lap up on the beaches after the main force of the waves is broken on the offshore reef slopes.

The oceanward reef margins drop off steeply into the depths, with slopes often as great as 45 degrees. Conditions for coral growth are optimal, and the offshore slope is blanketed with a profuse growth of many varieties. Elongated surge channels, oriented at right angles to the shoreline, give a striped appearance to the reef margin when viewed from the air. In the lagoon, the reefs drop off less steeply, and descend only a short distance to the bottom. The Tarawa lagoon has an average depth of only 6 to 8 fathoms.

Hydrography

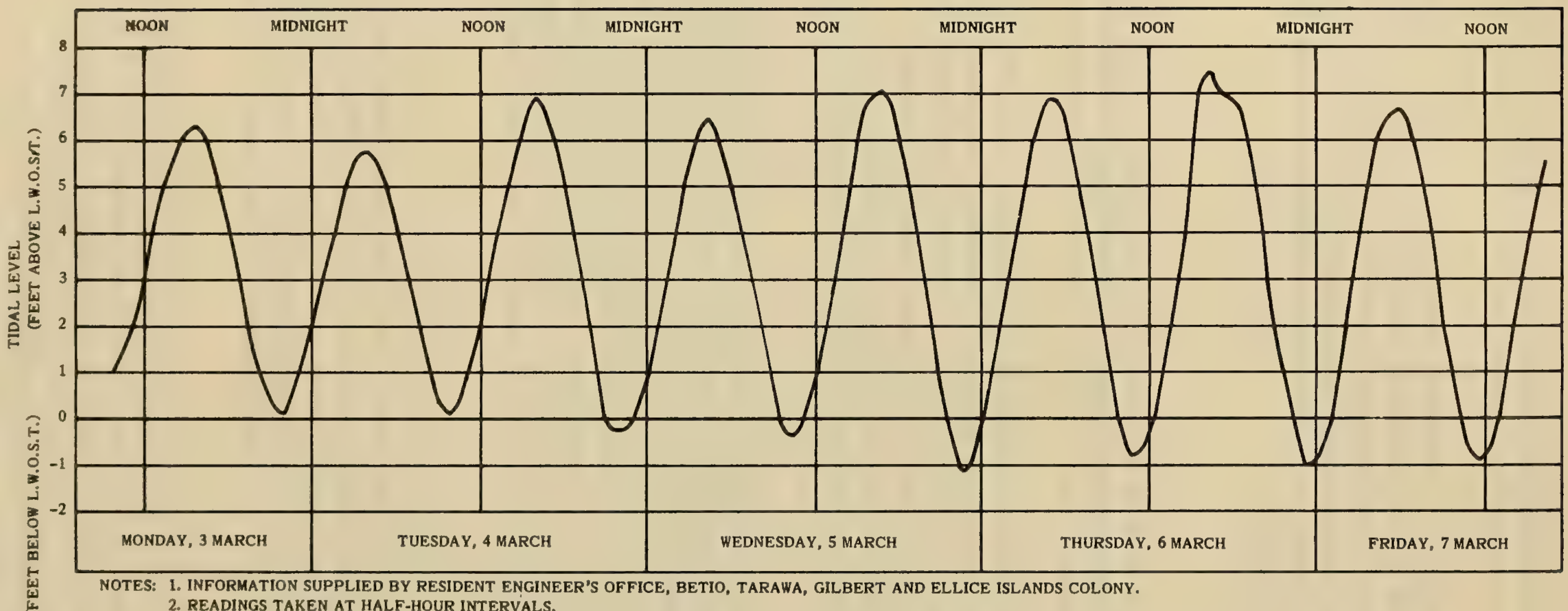
Offshore slopes, from the fringing reef down into deep water, are so steep around most of Tarawa that ships cannot possibly anchor. The exception to this statement is a small shelving area just off the lagoon entrance on the west side of the atoll in which ships can find anchorage.

The Tarawa lagoon is relatively shallow, in comparison with many atolls, and has depths ranging from a few fathoms to a maximum of about 12 fathoms in restricted areas. Many coral knolls rise near the surface, particularly in the portion of the lagoon southeast of Bikeman Island. The only part of the lagoon that is usable by ships and seaplanes lies southwest of a line drawn from Banreaba village (Eita Island) through Bikeman Island. Although in this area the most dangerous pinnacles have been marked, the HMS COOK, a Royal Navy survey vessel, is now resurveying all obstacles.

The average tidal range at Tarawa is about 4 feet, but the difference between high and low tides during spring tidal periods is 5.6 feet and during neaps is 1.8 feet (see figure 5). The datum used for the rather short periods of tidal measurement is a U. S. Coast and Geodetic Survey benchmark on Betio Island, on which the low water spring level is marked. The maximum tide measured thus far on Tarawa occurred on 11 December 1958 and reached 8.05 feet above datum; the minimum measured tide reached 1.0 feet below datum, thus indicating a maximum recorded tidal range of more than 9.0 feet. (An extremely low and irregular tide was a major contributory cause of the great number of casualties suffered by the U. S. Marines in their landing on Betio in November 1943.)

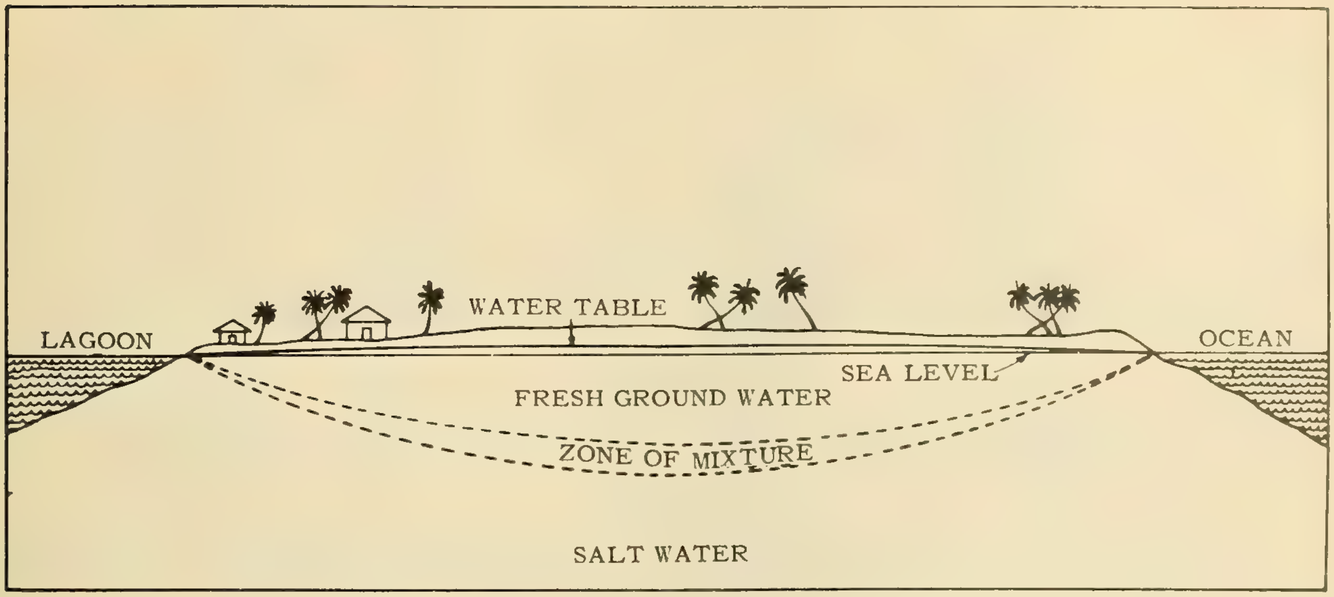
Little information is available on currents in the Tarawa area. It is known, however, that a coastwise current sets east on the south side of the lagoon, past Betio, Bairiki, and Teaoraereke, a fact documented by small spits built eastward from the Betio and Bairiki moles and, on a larger scale, by the long eastward-stretching spit shape of the two islets themselves. The current in the main entrance channel into the lagoon has a strength of 1.0 to 1.5 knots, changes in direction with the ebb and flow of the tide, but is no great problem to shipping since it follows the channel axis closely.

Because of the small size of islands, low elevation, and porosity of the coral bedrock, there is no surface stream anywhere on the atoll. The lens of fresh water which accumulates and floats above the salt water, as a ground water table on each islet, must be mentioned as an important source of fresh water (figure 6). The lens tends to be much thicker and to contain fresher water in the centers of islets, whereas on the lagoon and ocean sides and at the long narrow ends of islands, the lens tends to decrease in thickness and to contain a greater amount of brackish or salt water.



NOTES: 1. INFORMATION SUPPLIED BY RESIDENT ENGINEER'S OFFICE, BETIO, TARAWA, GILBERT AND ELLICE ISLANDS COLONY.
2. READINGS TAKEN AT HALF-HOUR INTERVALS.

Figure 5. Record of Tidal Level in Betio Harbor Basin for Period of 3 to 7 March 1958.



-- Taken from Military Geography of Northern Marshalls.

Figure 6. Idealized Section of the Ghyben-Herzburg (Fresh Water) Lens in an Oceanic Island.

Although excessive use of the fresh water may disturb the lens, and long periods of drought will cause it to gradually disappear, it must be emphasized as a significant source of water on islands notable for their water shortage.

Climate

Tarawa lies in close proximity to the equator and has a typical oceanic equatorial climate, characterized by mildness and uniformity of temperatures but a considerable variation in rainfall. Throughout the year, afternoon mean temperatures are in the high 80's and nighttime low figures are about 76 degrees; temperatures over 95 and under 68 almost never occur, and the very consistent easterly winds moderate the heat and provide a pleasant sensible temperature. The mean annual rainfall is 64 inches, a somewhat deceptive figure since the recorded range of annual rain is from 15 inches (1950) to 115 inches (1948); droughts are a matter of periodic concern in the Central Gilbert Islands.

Wind directions are generally from east or southeast, with speeds in winter (February) averaging 17 knots, in summer about 10 knots. Although many typhoons originate close by, to the north and west of the Gilberts, none has ever been recorded at Tarawa. Both overcast and cloud-free days are rare, and the normal situation is a scattered-to-broken system of tradewind woolpack clouds, often building up as thunderheads over lagoons or during the warmer afternoon period.

Biota

The vegetation of Tarawa may be described in simplest terms as a man-made forest of coconut palms, planted wherever they will grow. Without question, the coconut palm is the dominant and most characteristic plant on the atoll. Although in the interior the coconut palms grow vertically, reaching heights of 60 to 90 feet above the ground and casting such a dense shade that other plants

often grow beneath them only with considerable effort, along the ocean and lagoon shores they lean out toward the light in long and graceful curves, in places actually extending out over the water. Other plants, of course, are present on the atoll, one of the most characteristic being the salt bush, *Scaevola,* which occurs in profusion on the ocean beach ridges and to a lesser extent on the lagoon side or sparsely scattered among the coconuts. Pandanus, with its curious stilt-like maze of stems, is found where light is adequate; it provides both food and excellent thatch to the natives. A few larger trees such as *Pisonia* and *Calophyllum,* with its large symmetrical glossy leaves, are scattered through the interiors of the islets. Mangroves are found near the lagoon where mud flats provide a favorable situation; their intertwined stilt roots create almost impenetrable swamps.

The diagram of figure 7 illustrates some of these relationships, and appendix A presents details of the plants found on Tarawa.

Animal life on Tarawa, if domestic cats and dogs are excluded, is restricted to small lizards and rats, but fish of a wide variety are caught in the open ocean and particularly in the lagoon. A detailed listing of species is to be found in Randall* (1955).

Bird life on Tarawa is largely restricted to sea birds. Graceful white terns, noddies, gannets, and the piratical frigate-bird, long tailed tropic-birds, shearwaters, and petrels make up the dominant types. A few land birds migrate through the Gilberts and are to be seen occasionally.

OWNERSHIP AND POLITICAL STABILITY

Tarawa Atoll is a part of the Gilbert and Ellice Islands Colony of the United Kingdom. The colony, which is under the jurisdiction of the High Commissioner for the Western Pacific, at Honiara, Guadalcanal, is administered by a Resident Commissioner, whose headquarters are located in the Secretariat at Bairiki, Tarawa (figure 8). For administrative purposes, the colony is subdivided into four districts (Gilbert and Ellice Islands, Ocean Island, Line Islands, and Phoenix Islands), each of which is administered by a District Commissioner. The office of the District Commissioner for the Gilbert and Ellice Islands is maintained at Betio, 3 miles west of Bairiki.

The Resident Commissioner of the Colony, Mr. M. L. Bernacchi, was on leave at the time of the author's visit in August 1959. His office was occupied by Mr. R. Davies, Acting Resident Commissioner, whose regular position is Secretary to Government. Appendix B lists key personnel of the colony and their acting and regular positions in the government.

The Gilbert and Ellice Islands Colony has as much political stability as perhaps any colony under the British flag. Although a serious strike occurred on Ocean Island in 1948, no such incident has occurred since, and it would appear that political unrest may be considered nonexistent at Tarawa.

* See Selected Bibliography herein.

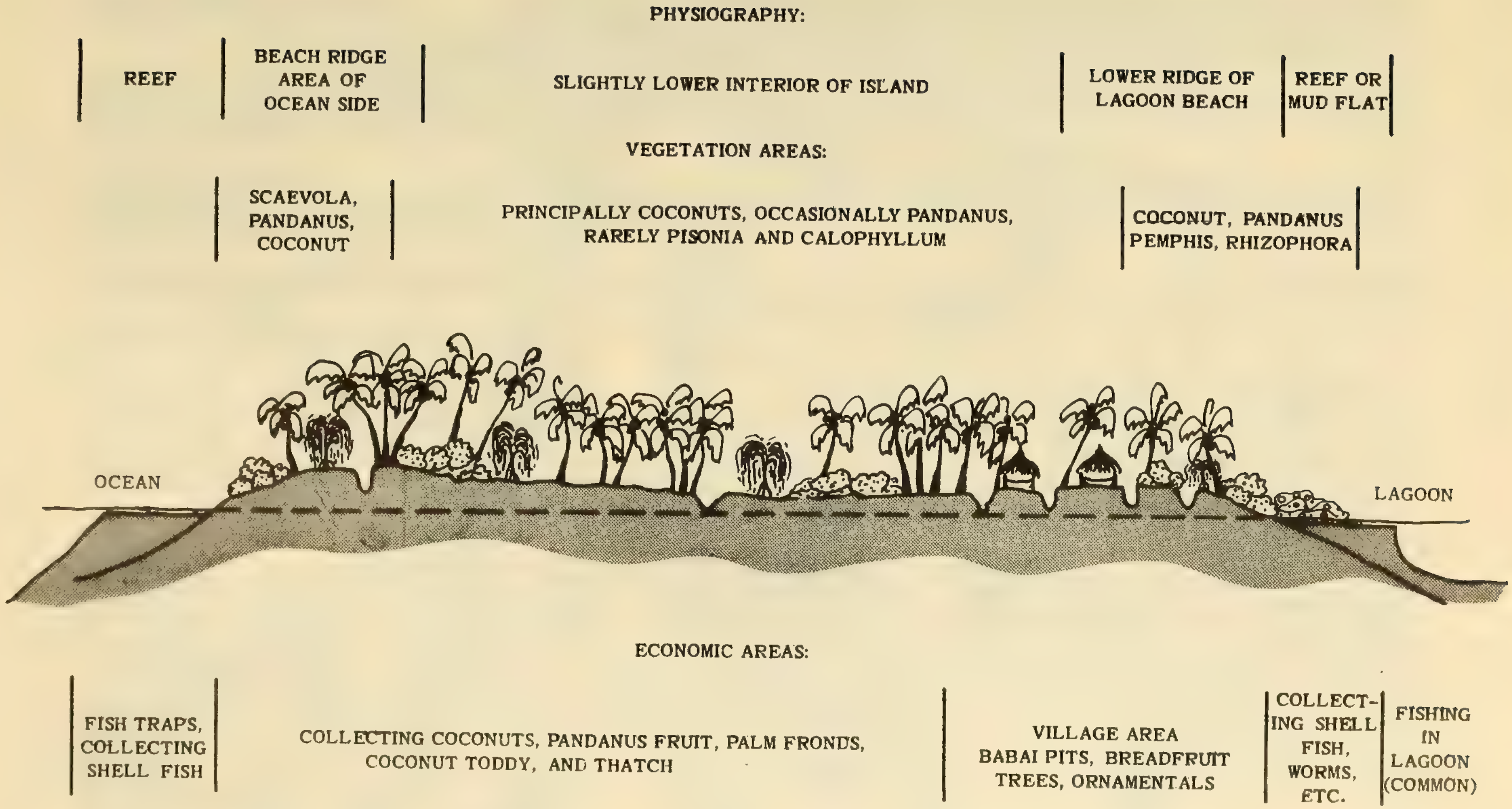


Figure 7. Physiognomic and Economic Cross-Section of a Typical Island in Tarawa Atoll.

Figure 8. Secretariat for Gilbert and Ellice Islands Colony (Headquarters of Resident Commissioner) at Bairiki on Tarawa Atoll.

POPULATION AND CULTURAL ATTITUDES

The Gilbert and Ellice Islands Colony is unusual because the Gilbert Islands are inhabited by Micronesian people whereas the Ellice Islands have a Polynesian population. The nearly 5,000 Polynesians are a minority in the colony as compared with the nearly 37,000 Gilbertese. With 576 Caucasians and some 81 Chinese added, the population of the colony at the end of 1958 was estimated at 42,546.

As the seat of government, Tarawa has had a notable influx of population, particularly since World War II, and now has a population of 7,125 persons, of whom 141 are Caucasians. Most of the population is Gilbertese, but a considerable number of Ellice Islanders also live on the atoll. The greatest concentrations of people, including most of the Caucasians, live on the southern rim of the atoll at Betio, Bairiki, or Bikenibeu. Figures 9, 10, and 11 are maps of these areas.

Details of the colony's population, by islands, and of population trends from 1931 to 1958 will be found in appendix C.

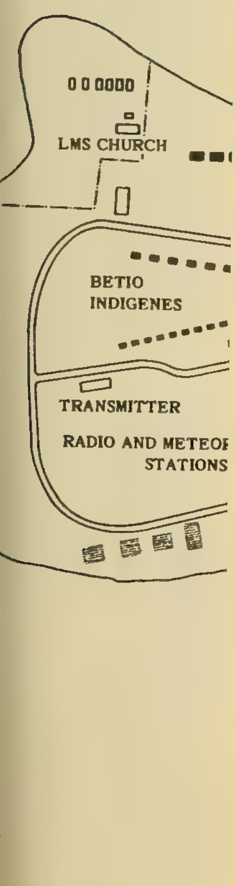
The available labor force in Tarawa and neighboring atolls is rather sizeable. Above the needs of the communities themselves, some 300 laborers are available from Tarawa alone, and with short notice it is possible to obtain 80 from Maiana, 250 from Abaiang, and 130 from Marakei, neighboring atolls. Perhaps 2 per cent of these persons are semiskilled and of use as carpenters, truck drivers, and such. Although the government itself cannot act as a recruiter of labor, a local trading firm (Schultz and Wilder) might take a contract for recruiting as it has done in the past. Unskilled labor is paid at the rate of 7 shillings per day (Australian currency, exchanged at $2.25 per pound) or £8/5/0 (8 pounds, 5 shillings, 0 pence) per month. For long-term labor a more usual arrangement is to pay 7 pounds per month and supply food and housing. A local part-Caucasian person is usually desirable as labor boss because of his understanding of local customs and work attitudes.

Certain Gilbertese cultural attitudes must be respected if good relations are to be maintained with local people. Most of these are matters of courtesy common to most cultures; other are localized attitudes. Natives are not allowed by law (voted by themselves) to drink alcoholic beverages; hence, it is both illegal and ill-mannered to offer a native a drink. Since large physical size and manual dexterity are greatly admired, it is persons with these qualities who are able to deal most satisfactorily with the Gilbertese. A series of other local attitudes that are important for the visitor to observe is emphasized by Sir Arthur Grimble (see appendix D), who learned them during years of experience in the area.

LAND USE AND OWNERSHIP

A typical traverse of an islet on Tarawa would show coconut and pandanus occupying positions from just landward of the ocean reef flat to the edge of the lagoon (figure 7). On the lagoon half of the islet, babai pits (similar to taro pits) are commonly interspersed with the trees, which here include breadfruit and some ornamental varieties.

Villages are characteristically on the lagoon side, as are the roads or tracks connecting them, and generally contain from 15 to 50 houses constructed from palm and pandanus (figure 12). Each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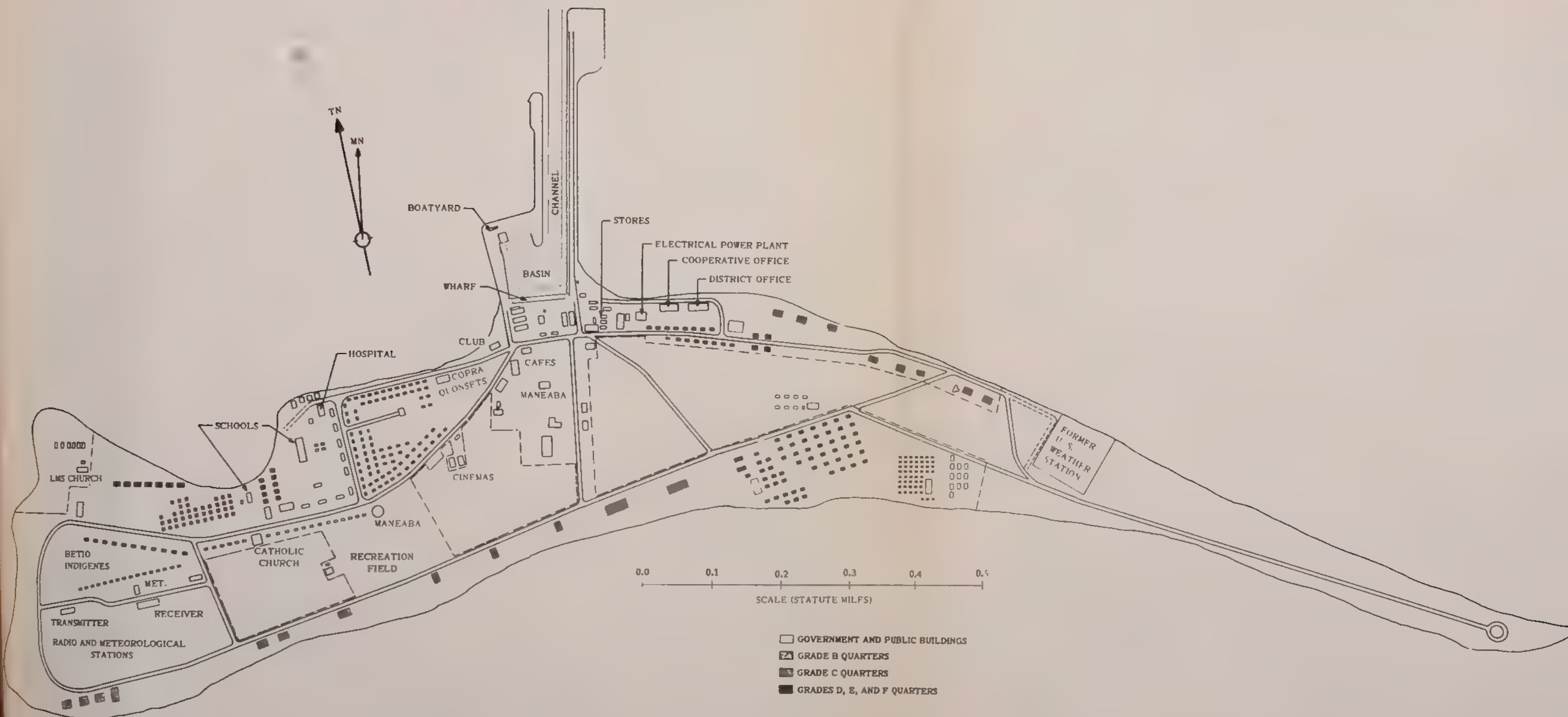
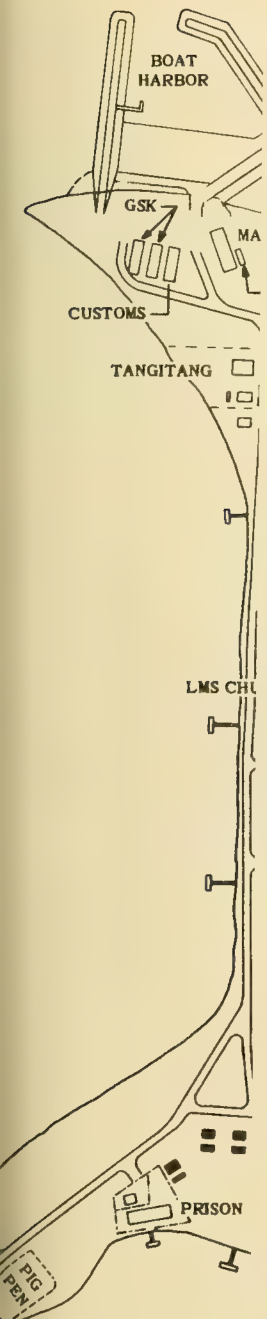


Figure 9. Map of Betio Area on Tarawa Atoll.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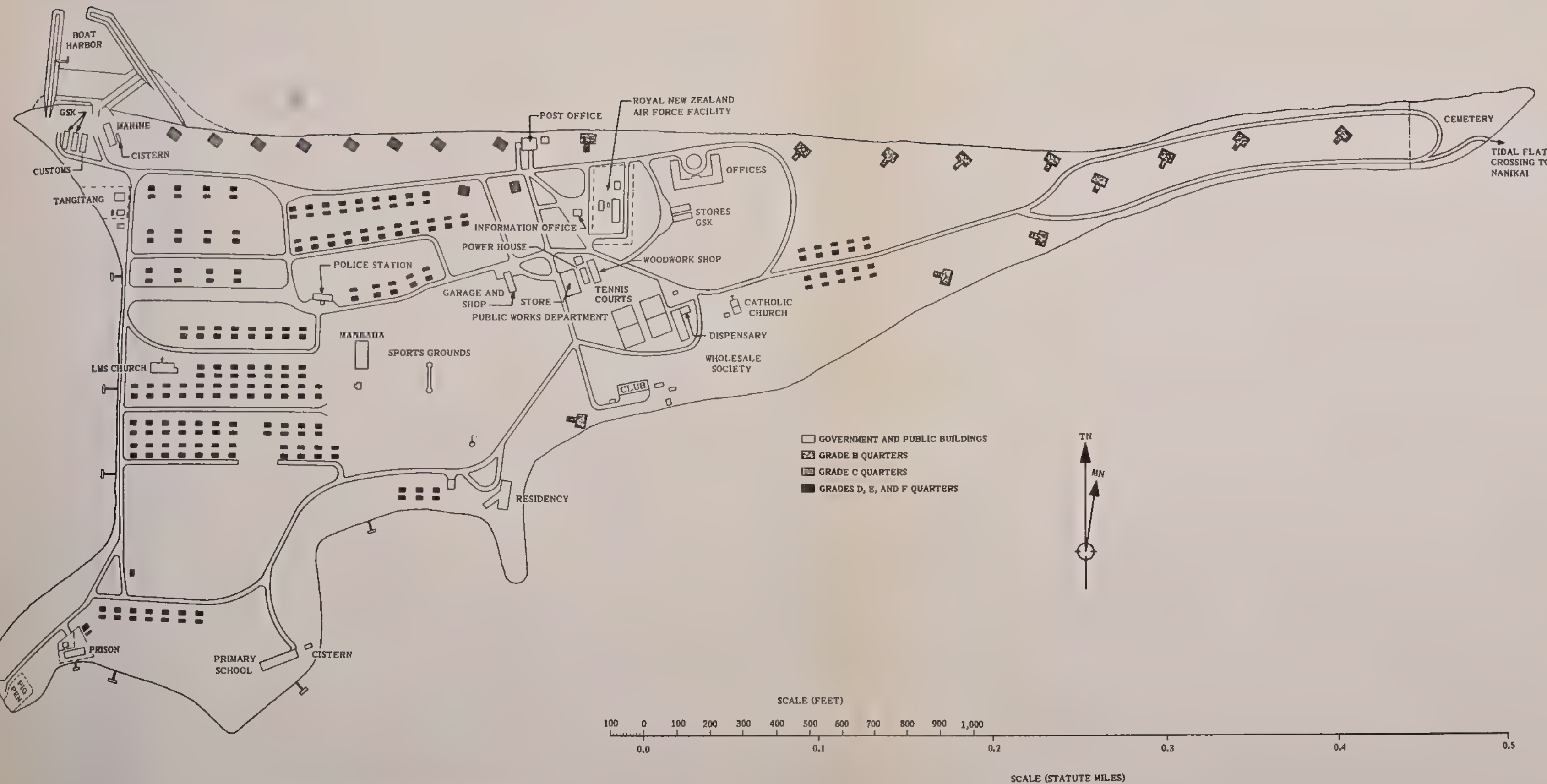


Figure 10. Map of Bairiki Area on Tarawa Atoll.

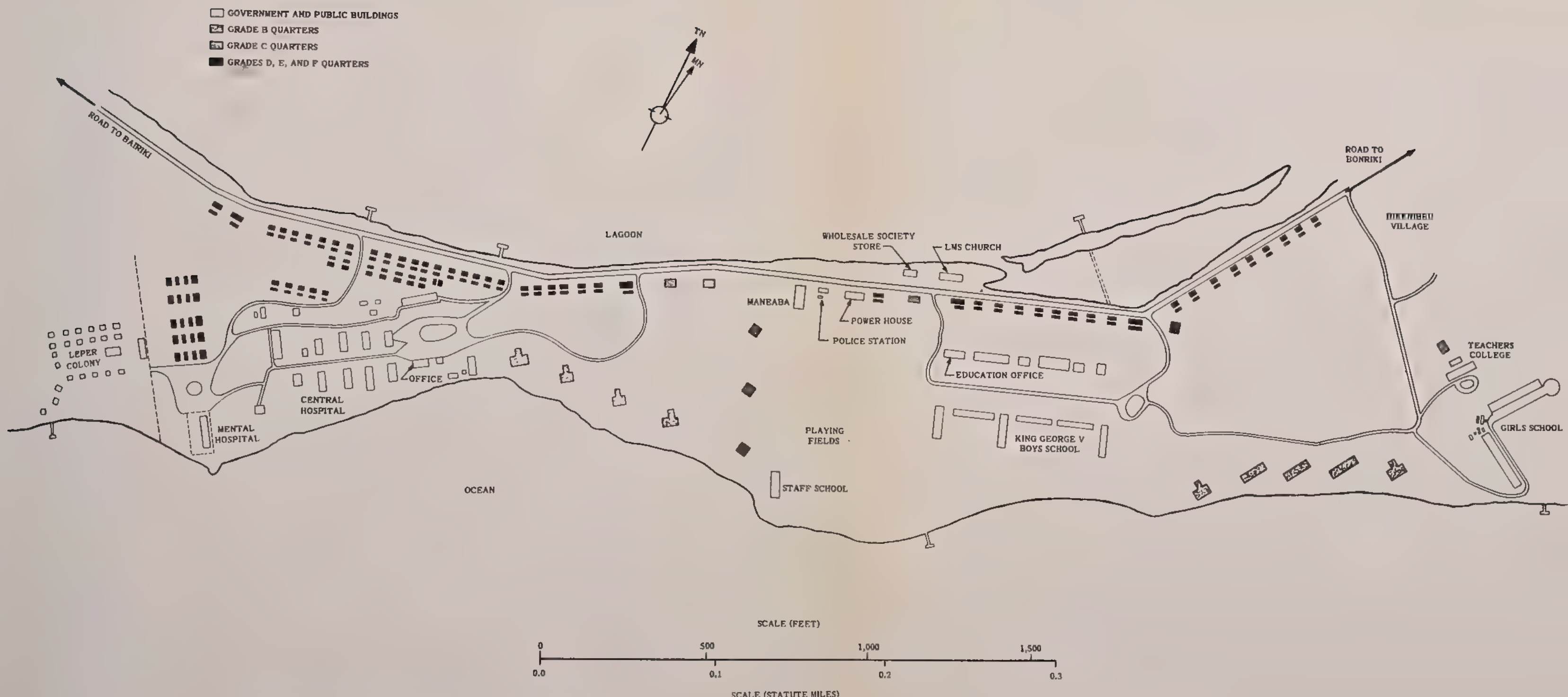
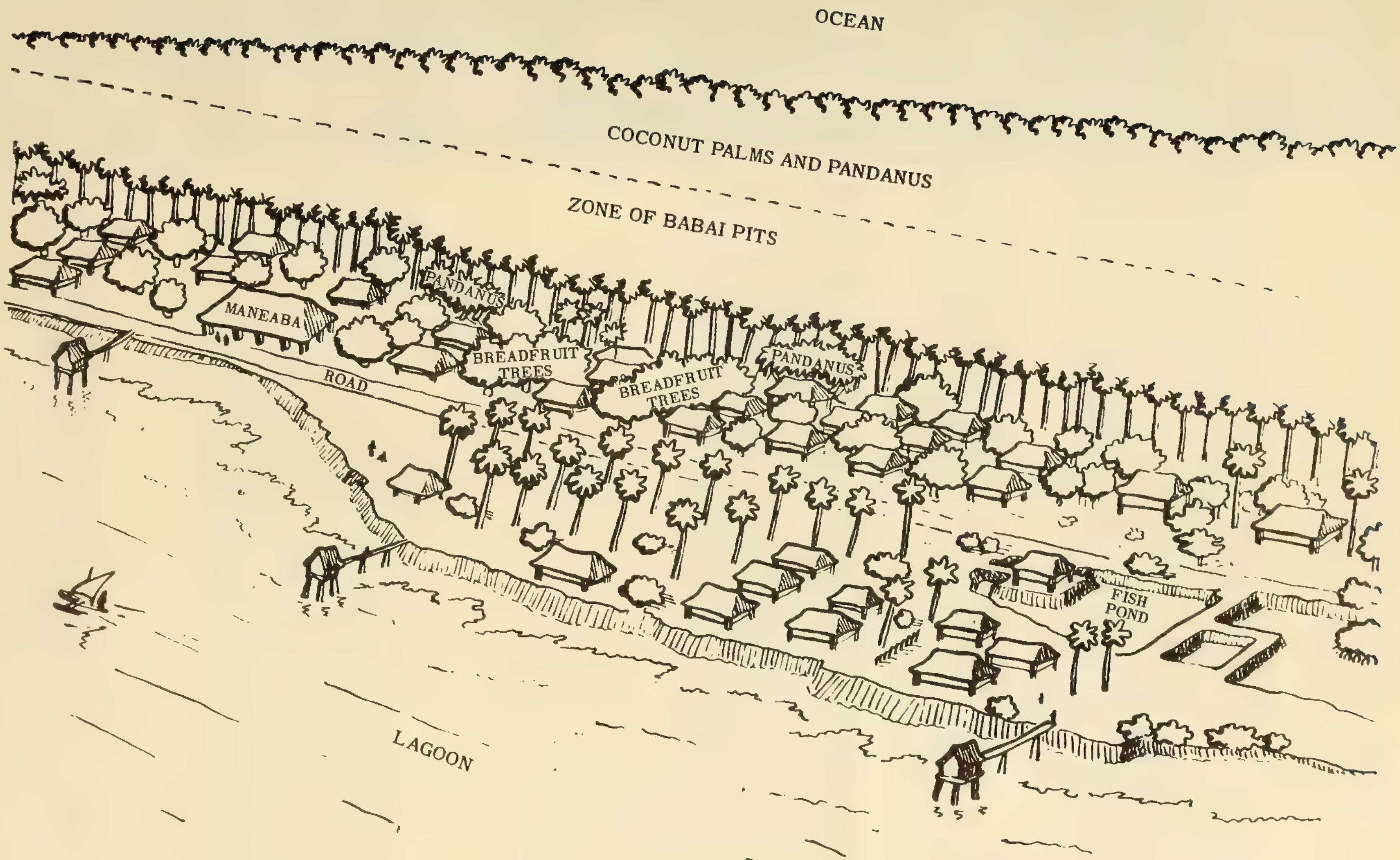


Figure 11. Map of Bikenibeu Area on Tarawa Atoll.



-- Taken from Atoll Research Bulletin No. 59.

Figure 12. Typical Village on Island in Tarawa Atoll.

house customarily shelters one family, while the maneaba or community house, the largest structure in the village, is the meeting place of the village leaders and is used for most manifestations of native group life. Less frequently it serves as a temporary shelter for visitors.

With large populations and small land areas, the Gilbert Islands have quite high population densities. Tarawa, for example, has a density of nearly 1,000 persons per square mile, and land is at a premium. Parcels of land are subdivided often, and a person may hold several tiny bits, scattered not only on various islets of an atoll but also on several different atolls. The typical organization of people into villages, with lengthy stretches of coconut woodland lying between, only serves to disguise a situation in which land is most valuable and often very difficult to acquire. Purchase of land is possible only for natives themselves, and litigation over land is the most common type of court action in the Gilberts.

Leasing of typical coconut land or bush land for governmental purposes is not a particularly difficult problem but does require a fair amount of time (measured in months). The normal rental fee is 3 pounds Australian per acre per year and, of course, is supplemented by payment for any damage such as the cutting of trees.

A considerable area of Tarawa is currently under lease to the British government. All of Bairiki and Nanikai Islands are leased, but the former is completely utilized by the Crown and most of the latter probably will be soon. About 60 per cent of Betio Island is leased, but most of the eastern spit, on which at present only scrub and a few coconuts grow, is unleased and vacant. In the Bikenibeu area, Crown leasehold extends from the leprosarium east to the school and training college area, while at Bonriki only the airstrip itself and the adjacent causeway are under Crown lease (figure 13).

FACILITIES AVAILABLE

Transportation

Sea

Deep-draft vessels cannot enter the Tarawa lagoon but may find anchorage in 12 to 20 fathoms of water just west of the entrance; here they lie in what is normally the lee of the atoll in relatively quiet water. The entrance channel to the lagoon has a least width of 1,000 feet and is deep enough to permit vessels of 26-foot draft to enter the lagoon proper at any time; spring tides will permit vessels drawing 28 feet to enter. Pilotage is available and, although not mandatory, is usually taken by captains who do not have local knowledge. The channel itself and the anchorage area of some 4 square nautical miles west and southwest of Bikeman Island have buoys or beacons marking obstacles (chiefly coral pinnacles). No moorings exist, and vessels ride to their own anchors.

At present, all cargo from ships of any size is taken ashore in lighters. Six barges, three with flat tops and three open, are operated by the Wholesale Society and range in capacity from 20 to 40 tons. Some eight launches are in use by Government or Wholesale Society, of which three, with lengths of 22 to 35 feet and engines powered at 20 to 40 horsepower, are capable of handling the barges. With the use of the present system, it is estimated by the Marine Superintendent that the cargo-handling capacity of the port is about 500 tons per day.

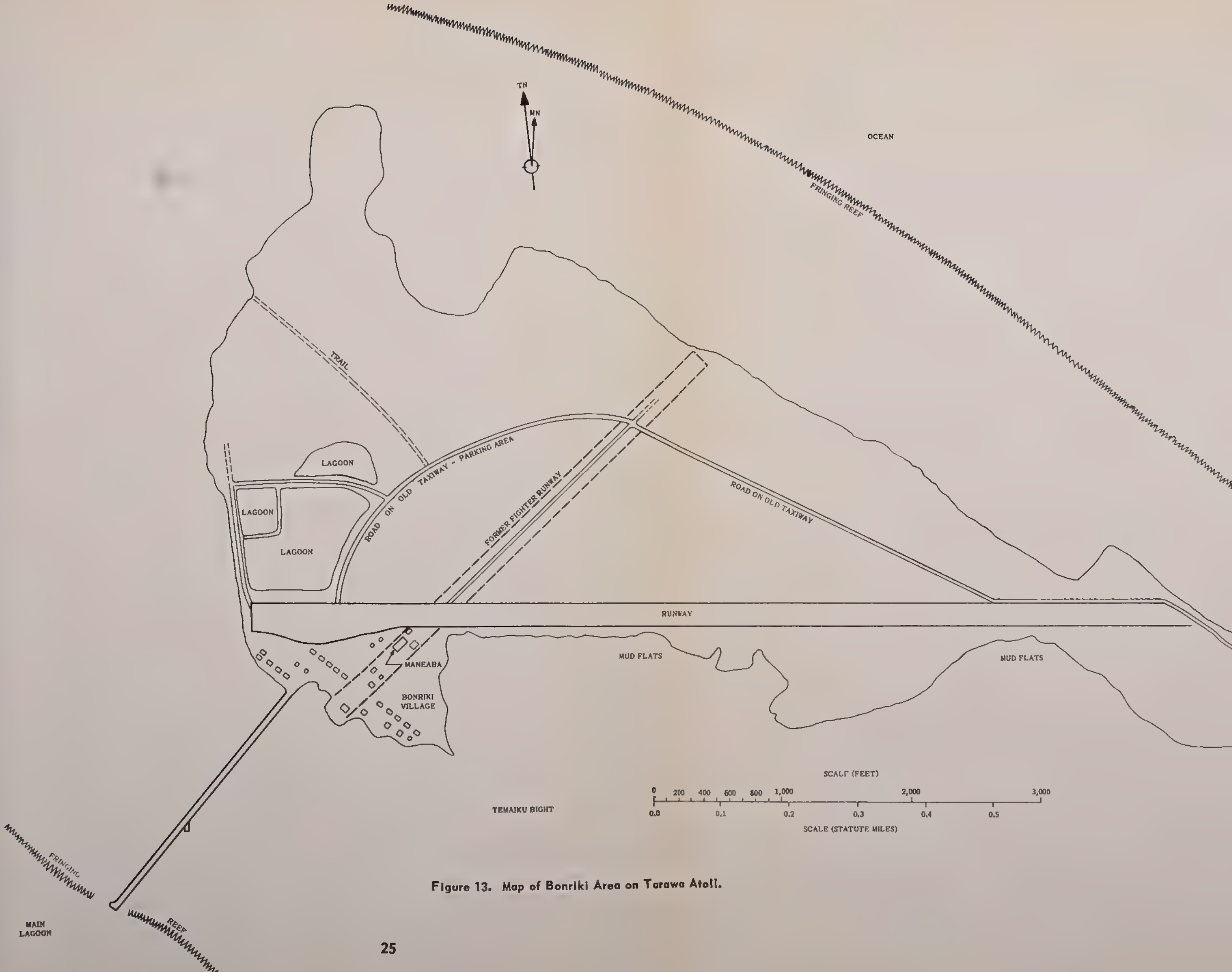


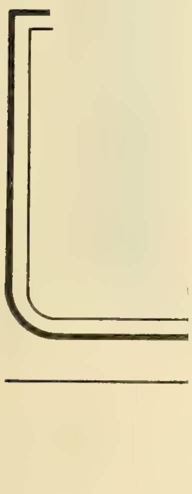
Figure 13. Map of Bonriki Area on Tarawa Atoll.

The principal harbor at Tarawa is an artificial one on the north shore of Betio Island (figure 14). A major project for harbor improvement, which is well advanced, will result in an entrance channel

Figure 14. Aerial View of Betio Harbor (Looking Southeast).

95 feet wide and 10 feet deep and an inner area 13 feet deep alongside the dock (figure 15). Some 300 feet of dock faced with sheet steel piling will have this 13-foot depth alongside, permitting any colony vessel to remain tied up at any stage of the tide. When completed, the harbor area will be well lighted, will have power lines and a transformer on the dock, and will have water lines for docked vessels to fill their tanks. (The present system requires water to be taken offshore to ships in a 15-ton capacity water barge.) Only one small 1-ton mobile crane is available at present, and future plans call for ships to handle all cargo with their own gear.

Copra is the principal outgoing bulk cargo, and sugar and flour are the principal incoming bulk cargoes; all of these are packed in sacks and handled manually. Repair facilities include the Wholesale Society boatyard, which can overhaul vessels up to 35 feet in length and can perform woodworking operations, replace planking, and the like. The Government Workshop nearby, which has metal working equipment, can repair drive shafts and can overhaul engines (figure 16).



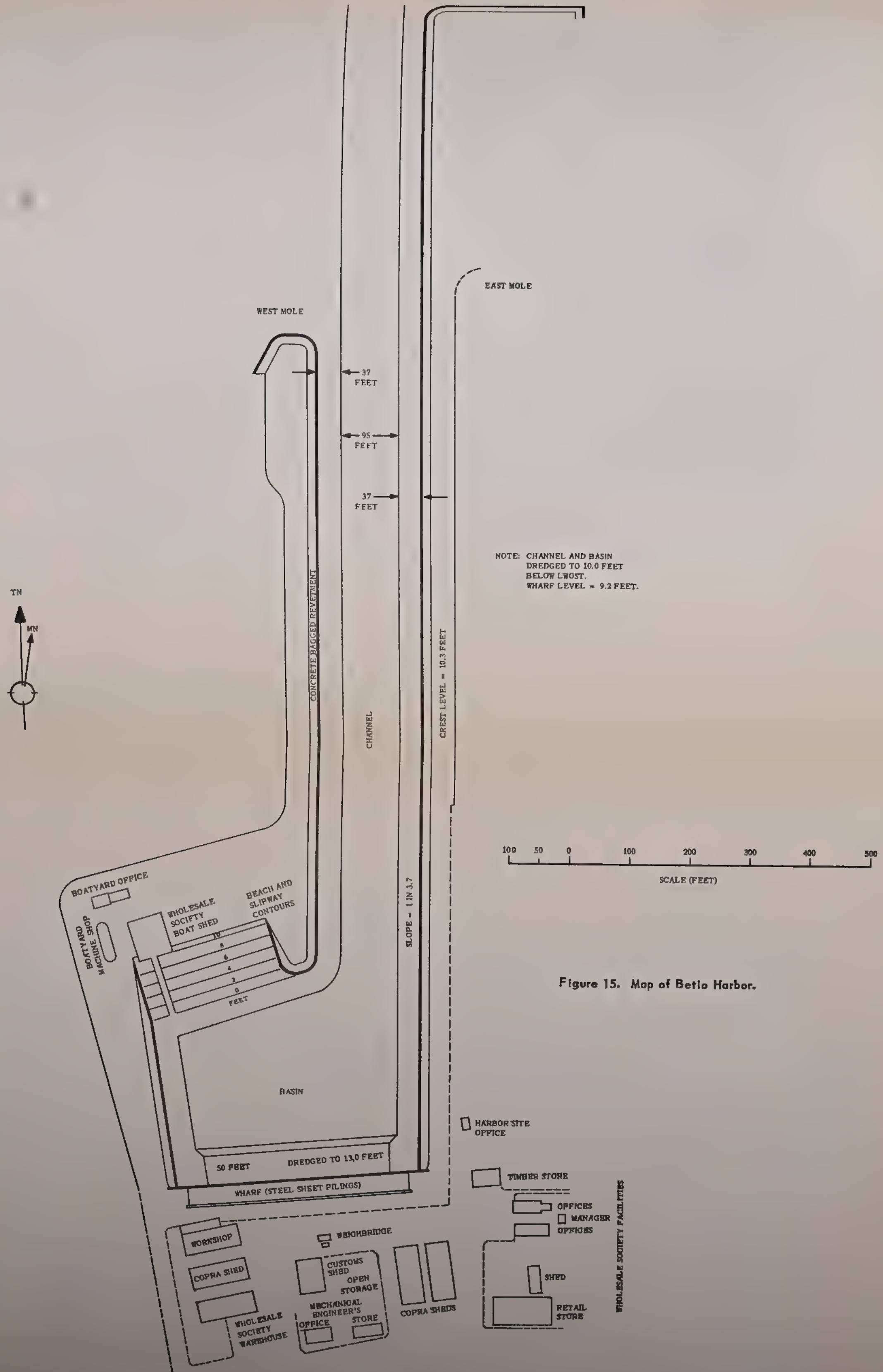


Figure 15. Map of Betio Harbor.

Figure 16. Boatyard and Ways Operated at Betio by the Wholesale Society.

Another portion of the harbor development scheme involves improvements to the boat harbor at the northwest corner of Bairiki Island (figure 17). Principal characteristics of the new harbor may be noted on figure 18. Since all connections between the colony headquarters at Bairiki and the district headquarters and the commercial activity at Betio require boat travel, a system of daily launch schedules, two boats each way, both in mornings and afternoons, has been set up to handle the traffic. A 1-shilling fee discourages joy-riders on the launches.

The mole extending into Temaiku Bight from near the west end of the Bonriki airstrip is now unused (figure 19).

Some nine ships, totalling 665 tons displacement, are in regular use in the colony for transportation among the islands (figure 20). They range in size from the 300-ton MOANA RAOI to the 10-ton FETUARO.

Figure 17. Boat Dock at Bairiki, With Launches Alongside and Dragline Working on Harbor Construction in Background.

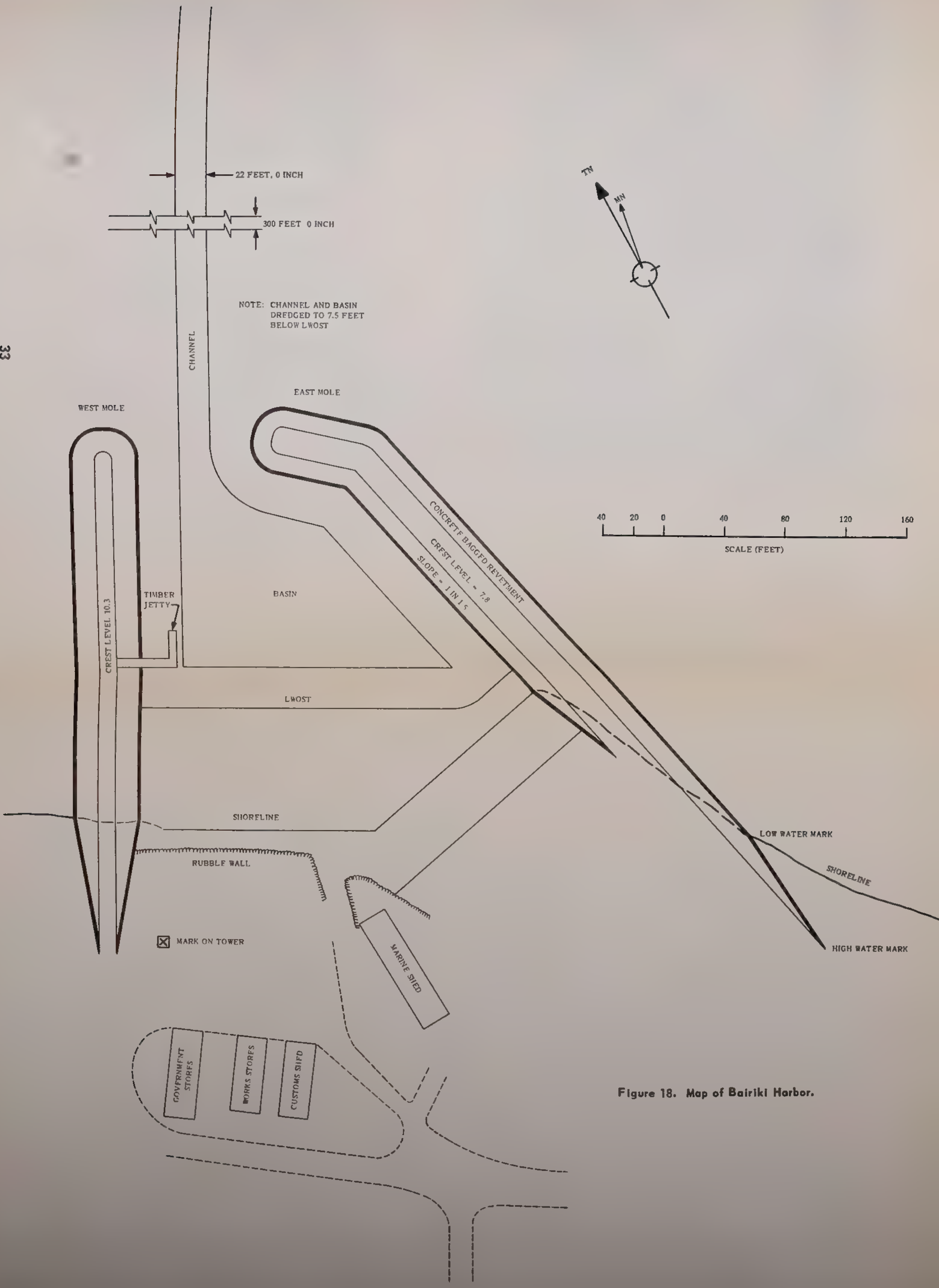


Figure 18. Map of Bairiki Harbor.

Figure 19. Unused Mole Near West End of Bonriki Airstrip (Looking Inland From Outer End of Mole in Temaiku Bight).

Figure 20. Interisland Transport Ships Operated by Gilbert and Ellice Islands Colony (From Left to Right: Nareau, Te Matapula, and Ninikoria).

Air

Of the several airfields constructed in the Gilbert Islands during World War II, only the one at Bonriki, near the southeast corner of Tarawa Atoll, remains today. All others, including the former Hawkins Field at Betio, have been replanted to coconuts and are completely unusable.

Bonriki Airfield today consists of one single runway, altitude 9 feet,oriented approximately east-west ($97^{\circ}-277^{\circ}$ true) (figure 21). The runway is 7,100 feet long, each end terminating at the water's edge without overrun. A certain amount of encroachment by coconuts and scrub has taken place along both sides of the runway, particularly about the center of the south side, but a clear width of 180 feet is still available for the entire length. The runway is made of compacted coral, which is still in good condition despite little maintenance since the war (figure 22). The bearing strength is unknown, but a 4-engine British aircraft landed on the strip in early 1959 and a Grumman UF-type amphibian aircraft landed on it three times in August 1959. American C-54's have used the field repeatedly in recent years.

The former fighter strip at Bonriki, extending northeast-southwest and intersecting the main runway, has been replanted in coconuts except for a poor road down the center. The southeast-northwest taxiway, which formerly connected the easterly portions of the two strips, and the extension of it, in a curve to west and south, which served as taxiway and parking strip, also have been replanted except for a 2-lane automobile road down the center (figure 23). Thus, except for a slightly wider area near the west end of the main airstrip, the airfield has no taxiways and no parking area (figures 24 and 25).

Except for wind socks at each end of the runway, the airfield has no other facility. Communications from aircraft to the island are with the radio station at Betio. When enough notice is given, a truck with soda-acid fire extinguishers is placed at the field to give some measure of fire protection. Again, when proper notice is given, small quantities of 100-octane aviation gasoline in drums can be made available at the field.

A seaplane landing area, used regularly by aircraft of the Royal New Zealand Air Force, is laid out in the lagoon to the north of Bairiki Island. A map of the system of buoys marking coral pinnacles and indicating the two principal directions for landing and takeoff is shown in figure 26.

Land

The road net on Tarawa consists of simple street networks at Betio and Bairiki and a road extending from Bonriki to Bairiki with interruptions at the channels between islands. For about two hours before and after each low tide, the water is low enough between islands for vehicles to cross, and it can be said that at these times a road extends for some 15 miles along the south side of the atoll (figure 27).

Most of the roads were constructed originally by the American forces during World War II. They consist of compacted coral, ranging from 16 to 24 feet in width. They have been maintained by use of a tractor-towed grader and toppings of reef mud in the chuck holes. The materials are tamped by hand because no roller is available. The slight amount of traffic gives so little wear that these rather simple maintenance methods suffice to keep the roads in good condition.

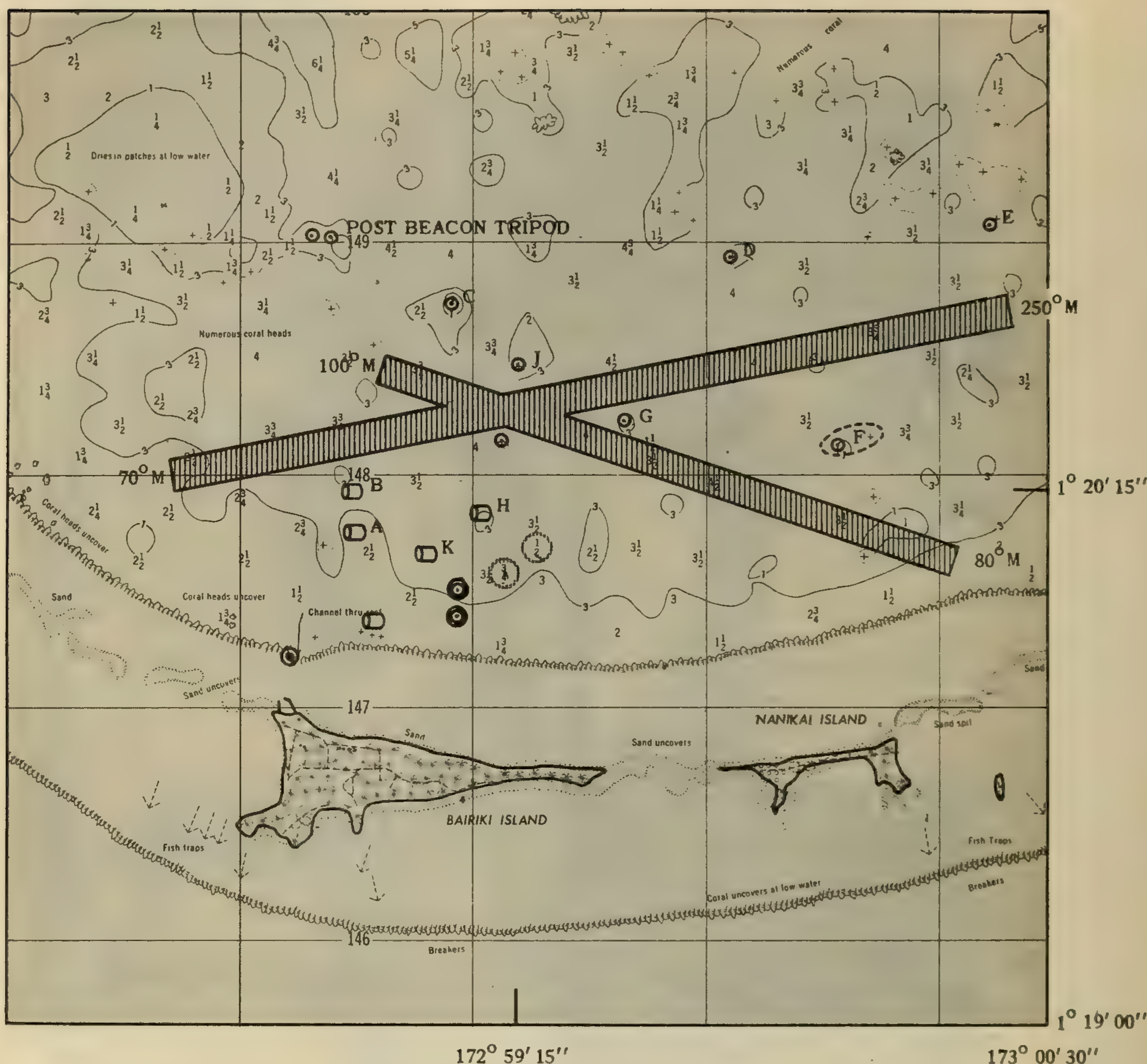
Figure 21. Aerial View of Bonriki Airfield.

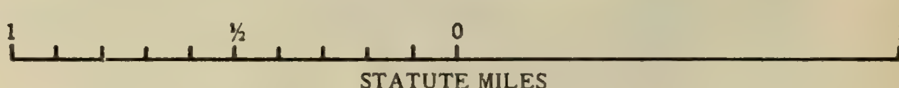
Figure 22. Surface of Runway at Bonriki Airfield (Looking Eastward).

Figure 23. Central Portion of Runway at Bonriki Airfield (Looking Northward).

Figure 24. West End of Runway at Bonriki Airfield (Looking Northward).

Figure 25. Slightly Wider Area at West End of Runway at Bonriki Airfield (Looking Southeast) (Note Truck With Fire Extinguisher at Extreme Left).





BUOY

BEACON

AIRCRAFT BUOYS

FLASHING RED BEACON

Figure 26. Map of Seaplane Landing Area North of Bairiki and Nanikai Islands Used by Royal New Zealand Air Force.

Figure 27. Land Rover in Passage Between Islands at Low Tide.

With the exception of 4 cars and 1 small truck at Betio, all vehicles on Tarawa are owned by the Government or the Wholesale Society. The vehicles are listed as follows:

	Total on Island	3-Ton Truck	Land Rover	Car	Small Truck	Ambulance
Betio	16	8	3	4	1	0
Bairiki	5	2	2	0	1	0
Bikenibeu	3	1	1	0	0	1
Total on Atoll	**24**	**11**	**6**	**4**	**2**	**1**

Maintenance of vehicles is performed at garages operated by the Wholesale Society or Government at Bairiki and Betio. The Government Machine Shop at Betio can rebuild engines and perform more complex repairs.

No true garage storage exists on the atoll, but shelters that keep off sun and rain exist for most vehicles. A gasoline pump at Betio and drums at Bairiki and Bikenibeu supply fuel.

Meteorology

All meteorological services for the colony are operated by the New Zealand Meteorological Service as part of its responsibilities with the South Pacific Air Transport Command, the over-all weather coordinating group for the South Pacific. Synoptic observations are made from 10 stations within the colony, of which Tarawa is one. Observations are made of temperature, pressure, pilot balloon flights (Tarawa and Funafuti only), rainfall, and visual observations of wind speed, direction, visibility, and cloud types. Among the instruments at Tarawa are a recording rain gage, recording barograph, and typical thermometers.

The colony staff consists of one European and 20 islanders; at Tarawa are the one European, three observers, and two trainees. The observation schedule (local times) calls for piball flights at 0530, 1030, 1630, and 2400; for synoptic observations at 0600, 0900, 1200, 1500, and 1800; and for climatic data at 0900.

A United States meteorological station was maintained on Tarawa intermittently during 1951, 1954, 1956, and 1958 by personnel of Joint Task Force SEVEN. During these periods, rawinsonde and radiosonde observations were taken two or four times daily. When the station was abandoned in 1958, all the equipment was removed and only the buildings were left at the location. The map (figure 28) and photographs (figures 29 and 30) present data on the past and present conditions of this station.

Communications

Radio communications in the Gilbert and Ellice Islands Colony are well developed, and regular schedules are maintained between Tarawa and Honiara, British Solomon Islands Protectorate, and with Nandi and Suva in Fiji. Within the colony, some 34 stations comprise a good communications net and provide for ship-to-shore or aircraft communications. On Tarawa, because of the necessity for maintaining good communications between individual islands, with their several government offices, a VHF system is maintained which connects Betio, Bairiki, and Bikenibeu. The HF transmitting and receiving stations for Tarawa are located at Betio, toward the west end of the island (figure 31). Considerable detailed technical information on the Tarawa radio communications is given in appendix E.

Very little telephonic communication is available on the atoll. Two 6-line intercom units are utilized between various offices in the Secretariat at Bairiki, and a few field telephones connect important points such as the Secretariat, Post Office, and dock area. Betio also has a few field telephones connecting similar locations.

Storage

No open bulk storage facilities are specifically laid out on Tarawa. Although a reasonable amount of space for storage is available, this space might not be in the immediate dock areas at Betio and Bairiki, because these areas are relatively congested. In the Bonriki area, ample open storage area is available close to the causeway and airfield.

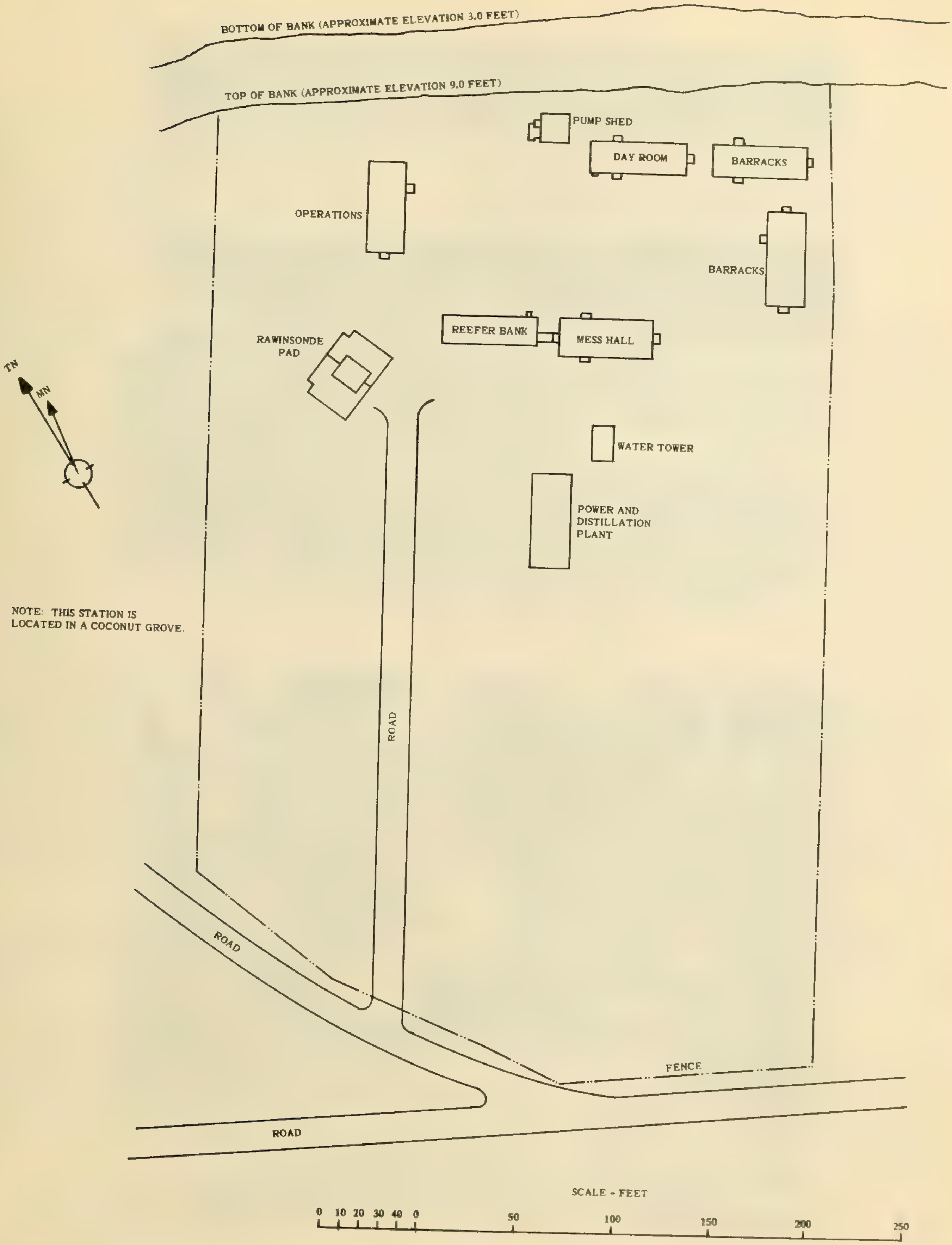


Figure 28. Map of U. S. Meteorological Station at Betio.

Figure 29. Aerial View of Meteorological Station at Betio.

Figure 30. Buildings in Meteorological Station at Betio.

Figure 31. Transmitter Building at Betio.

Most covered storage or warehouse capacity on Tarawa is in the form of Nissen (Quonset-type) buildings (figure 32). At Bairiki, five large Nissen warehouses (24 by 60 feet) are used for governmental purposes, one covered shed (40 by 75 feet) is used for lumber storage, and a large Wholesale Society store and storehouse are combined. Storage facilities at Betio comprise eight large Nissen copra sheds or warehouses (40 by 100 feet), a customs shed (40 by 60 feet), about 10 smaller Nissen warehouses (20 by 100 feet), and a thatched timber storage area (about 30 by 50 feet). Most of this storage area is filled to capacity. Half or perhaps an entire copra shed (Nissen hut, 40 by 100 feet) might be made available temporarily in case of emergency.

Refrigerated storage on Tarawa is limited to two 150-cubic-foot reefers at Betio, housed in a 24-by-30-foot building. Another 300 cubic feet of storage is expected to be available by October 1959.

All petroleum products are now stored in drums at an open-storage area of 150 by 240 feet (figure 33). However, plans are being considered for bulk storage of POL near the harbor, including a 120,000-gallon tank for ship diesel fuel. Normal stocks of POL products in 55-gallon (U. S.) drums, are maintained as follows:

	55-Gallon Drums	5-Gallon Tins
100-octane aviation gasoline	200	
Aviation lubrication oil	6	
Automobile gasoline	300	
Kerosene	400	60

Figure 32. Nissen Building Used as Warehouse Near Dock at Bairiki.

Figure 33. Open Storage Area for Petroleum Products at Betio.

	55-Gallon Drums	5-Gallon Tins
Ship diesel oil	2,000	
Ship lubrication oil	40	
Denatured alcohol	80	
Sundry specialized greases and oils		

Utilities

Water Supply

Water supply on Tarawa is a problem because of low and irregular rainfall, small land area, and lack of surface streams or lakes. The basic source of water is the freshwater lens which overlies the salt water in the substrata of each island. Wells are dug down to this water table. Some 300 wells in all serve the general population for all purposes in the three areas of Betio, Bairiki, and Bikenibeu. Well water is hard and tends to get progressively more brackish as a drought period persists. Water trucks, filled from the larger wells, distribute water to the individual government house tanks several times a week.

All drinking water for the Caucasian population is rainwater obtained from catchments on the individual houses. It is stored in an 800-gallon tank near each kitchen. Even this water is filtered and boiled before it is used by most Caucasians. Three large cisterns at Bairiki and Betio, which have a capacity in all of about 150,000 gallons, are used to store water obtained from the government catchment areas.

During the periods in which the U. S. Meteorological Station on Betio was occupied, all of the water used by the unit was distilled from sea water.

Electric Power Supply

The electrical systems installed on Tarawa have the following characteristics: 415 volts, 3 phases (or 240 volts, 1 phase), 50 cycles per second, with distribution on a 4-wire (3 phases plus neutral) main line. Transformers are available which can provide 110 volts for small loads.

Betio is provided with two 82-kilowatt Ruston generators. The peak load is estimated at a little more than 60 kilowatts, leaving one generator as standby. In addition, two 19-kilowatt Southern Cross generators are used as emergency standby equipment for the radio communications facility.

Bairiki has an 82-kilowatt main generator and a 69-kilowatt standby generator. Bikenibeu has an 82-kilowatt main generator, a 10-kilowatt standby generator for emergencies in the operating room at the hospital, and a 75-kilowatt generator on order which will be used as a standby.

In addition to the government offices, shops, docks, radio station, and other users, power is distributed to government housing at the three main government centers. Both Betio and Bairiki have service for about 18 hours per day; Bikenibeu has service for about 12 hours per day.

Sewage and Waste Disposal

Sewage from all Government Grade B (Caucasian) and Grade C (top native employees) housing is disposed of in individual septic tank systems, one for each house. All other persons on the atoll use latrines built out over the lagoon reef and connected by walkways to the shore. A septic tank system is installed at the site of the U. S. Meteorological Station.

Garbage is collected by truck twice a week and is burned on the reef. The unconsumed remains are carried off by the sea.

Maintenance Facilities

The principal maintenance facility is the Government Workshop located in the Betio dock area. Available equipment includes two metal lathes, a shaping machine, a vertical drilling machine, two grindstones, a valve grinder, an electric welding plant, and an oxyacetylene plant. The type of work accomplished here ranges from complete overhaul of diesel engines (up to 100 horsepower) to repair of vehicles and maintenance and repair of generators. Replacing parts is a problem because a relatively small stock is kept on hand.

The Wholesale Society (Betio) and the Government (Bairiki) have vehicle maintenance shops with compressors, grinders, battery-charging equipment, and grease racks or pits. The Wholesale Society boatyard at Betio and the Government carpenter shop at Bairiki have woodworking machines such a routers and planers.

Fire Protection

There is no formal group of personnel continuously on duty for fire protection. When an alarm is given, a group of laborers on each island assembles for fire-fighting under the supervision of a Caucasian. The two trucks (at Betio and Bairiki) which are used during the day for distribution of water to houses are left filled each night for use in an emergency. In addition, there are four 35-gallon extinguishers on wheels (2 at Bairiki, 1 each at Betio and Bikenibeu). As further protection, each Grade B house has two hand extinguishers (carbon tetrachloride and soda acid), and each Grade C house has a soda acid extinguisher. Among the smaller houses, a soda acid extinguisher is maintained for every 10 structures. Buckets are kept at hand in all main buildings. An alarm system is maintained. With the equipment outlined above, there have been few serious fires despite the apparent hazard of thatched roofs on most buildings.

Police Protection

Although the Superintendent of Police for the Colony is located on Ocean Island, the principal police officer for the Gilbert and Ellice Islands District, entitled Inspector of Police, has his headquarters on Tarawa. The forces for each of the main areas consist of: a Station Sergeant and 9 police at Betio; the Inspector, a Sergeant, and 15 police at Bairiki; and 1 policeman at Bikenibeu. A part-time local village policeman is stationed in each of the other villages on the atoll.

The principal jail for Tarawa, located at Bairiki, has a capacity of 21 male and 7 female prisoners at any one time.

Housekeeping Facilities and Personal Services

Quarters and Food Supply

Although the British have completed an appreciable program of construction of permanent housing on Tarawa, all housing is occupied and no facility is immediately available for even a small visiting party (figure 34). Some hundreds of houses have been built, but only 34 meet standards for occupancy by Caucasians. There is no hotel nor guest house of any description. Billeting of a visiting group would be difficult. Two qualifications to the above statements may be pointed out:

1. The buildings at Betio formerly occupied by the U. S. Meteorological Station are vacant at present and could provide shelter for an official party (figure 30). However, all equipment, bedding, messing, food, and the like would have to be brought in by the visiting group.
2. An official visiting party might be provided quarters, if plans were properly coordinated, at the Royal New Zealand Air Force facility at Bairiki (figure 35). These quarters were established for use by the crews of RNZAF aircraft which visit Tarawa approximately every two months on training flights. The facility, which has room for 6 officers and 15 enlisted men in two buildings, includes a separate cook and wash house (figure 36). Bedding and utensils are left in the buildings. All that is required of a visiting party is to supply its own food and to hire local labor as cooks and orderlies. If formal arrangements were made with the RNZAF at Lauthala Bay (near Suva), Fiji, it might be possible for a group to occupy these quarters between the periodic visits by the RNZAF.

Any visiting party of more than two persons would, at the least, have to supply its own food, and very probably would have to supply its entire bedding and messing needs.

Medical and Dental Care

The principal hospital for the Gilbert and Ellice Islands Colony is located at Bikenibeu, near the southeast corner of Tarawa Atoll. The staff is comprised of 5 Caucasians (2 doctors, 2 nurses, 1 pharmacist), 3 assistant medical officers (natives trained at the medical school at Suva, Fiji), 15 native nurses, 15 dressers (about the same as first aid men), and about 20 cooks, janitors, and other workers.

The hospital has beds for 6 Caucasian patients, 83 native patients, 15 mental patients, and, in an adjoining area, facilities for handling 70 leprosy cases. A fully equipped operating theater, X-ray machine, and facilities for simple laboratory tests comprise the major equipment at the hospital.

Operations such as appendectomies and hernias and maternity cases are routine for both Caucasians and natives, but more involved medical problems, so far as Caucasians are concerned, are handled by specialists in Australia or Fiji. An assistant medical officer, specialized in dentistry, does oral surgery and makes dental plates.

Laundry and Cleaning Services

No commercial drycleaning or laundry facilities exist on Tarawa. Local laundresses do all washing, houseboys do minor cleaning, and fancy cleaning is mailed to Australia or Suva for processing.

Figure 34. Grade D Government Housing Occupied by Gilbertese Couple in Foreground.

Figure 35. Royal New Zealand Air Force Quarters at Bairiki (Quarters for Enlisted Men in Center, With Officers' Quarters at Extreme Right and Cook House at Extreme Left).

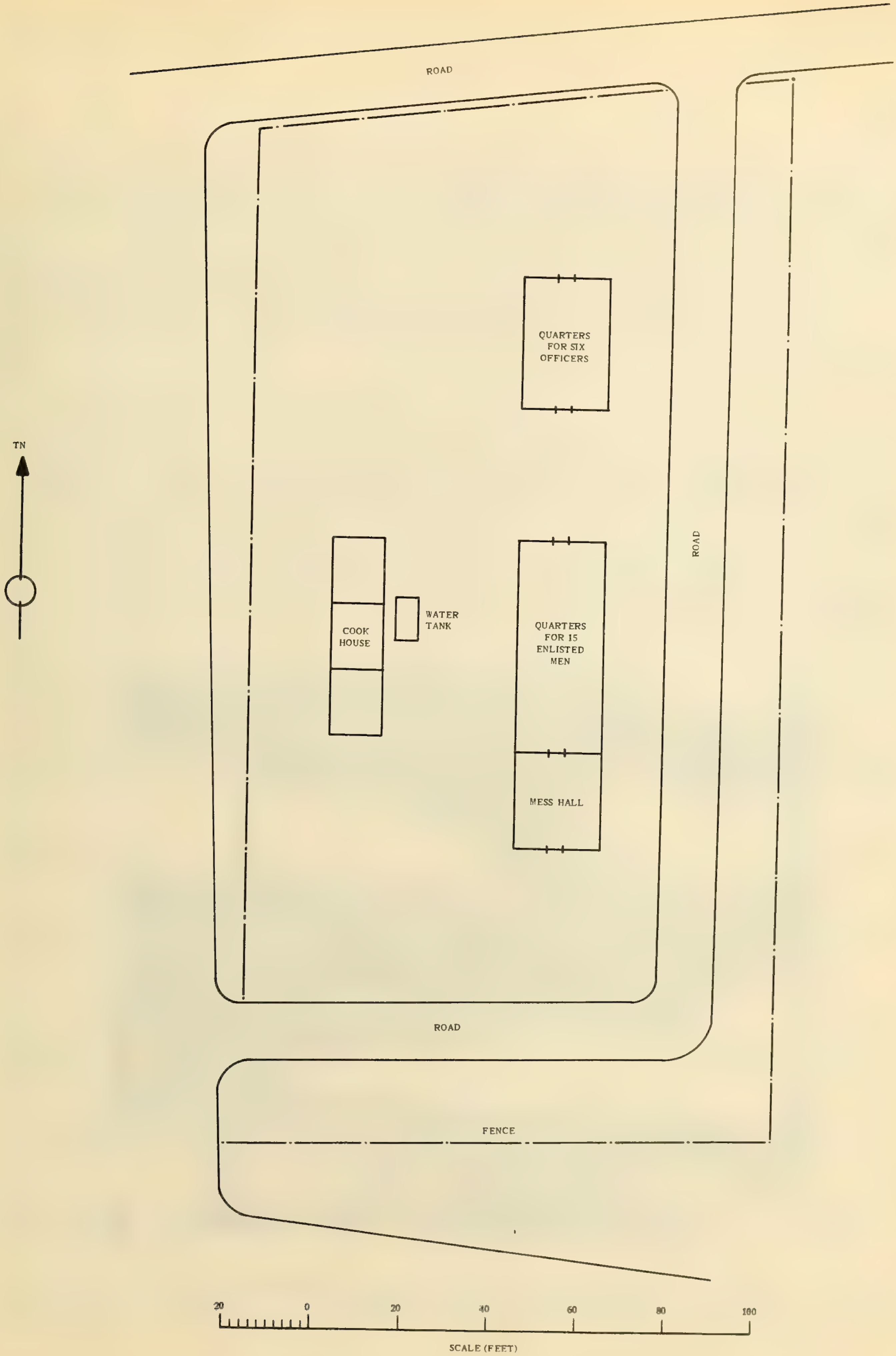


Figure 36. Map of Royal New Zealand Air Force Facility at Bairiki.

Religion

Although there are small congregations of perople who profess the Bahai, Church of God, and Seventh Day Adventist faiths, most of the population of Tarawa is divided approximately half and half between Roman Catholics and members of the London Missionary Society (closely related to Methodism).

A Catholic church is located in every village, and a small LMS church is located on every islet of the atoll. On Tarawa are a Catholic bishop, two priests, and about four nuns who are expatriates, and also Caucasian pastors of the Bahai and Church of God faiths. Native pastors represent the other religions.

Education

In Tarawa, no school is available which maintains European standards of education. Caucasian children, at about age 9, are sent off to boarding schools in Australia, New Zealand, or England.

The King George V School (figure 37) at Bikenibeu is the principal school for the colony. It provides secondary education to native boys from all over the colony. The Education Officer and Headmaster of the school are expatriates.

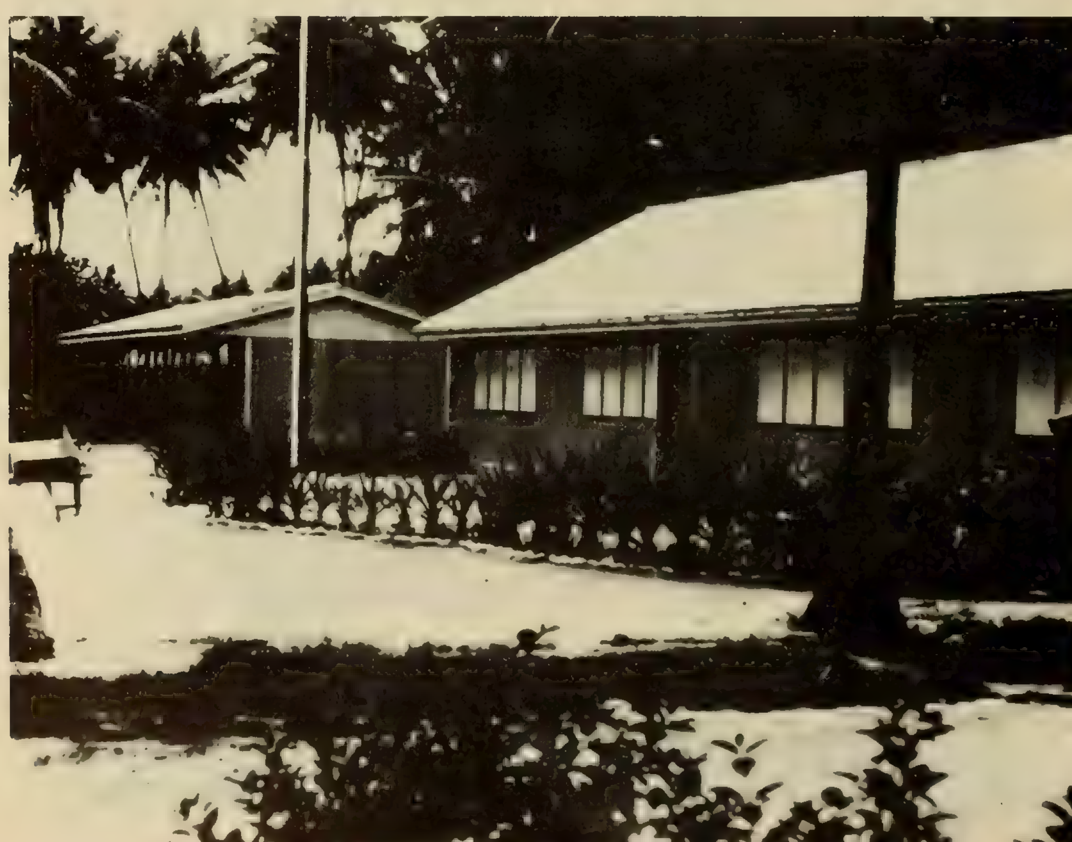


Figure 37. King George V School at Bikenibeu (Assembly Hall at Right and Administration Building at Left).

Recreation

Commercial recreation facilities are absent from Tarawa, with the exception of two open-air movie theaters at Betio and one at Bairiki. These theaters charge 12 cents admission and present programs dominated by old cowboy movies and adventure films. Caucasians have organized clubs at Betio and Bairiki which serve as focal points for social activities; each has a bar, billiards, darts, and other typical club facilities. Tennis courts are available at Betio and Bairiki, and sports grounds for cricket and rugby are located at these villages and at Bikenibeu. Fishing, sailing, and skin diving provide other recreational outlets.

Construction

Except for reef detritus used as aggregate for concrete, no construction material whatsoever is available at Tarawa. All cement, steel, and lumber are imported for specific jobs, and there is never any excess for casual purchase or use. Coral debris from the reefs is used to good advantage in concrete after it is washed and screened. Small (3/16-to-3/4-inch) and large (3/4-to-2-inch) sizes are used; fine particles and the few particles over 2 inches are discarded. Well water, fresh to brackish, is used in making concrete, but seawater can be used if necessary; in the latter case, the curing period is longer and the early strength of the concrete is lower.

All construction equipment has been imported for special purposes, principally for the harbor construction project. The equipment list comprises a 5/8-yard dragline, a 50-horsepower bulldozer with winch, 2 Morris 3-ton tippers, 4 concrete mixers (10-cubic-foot), a trailer-mounted compressor, and a diesel piling hammer. The piling hammer, a Delmay model D5, is used for driving the steel sheet piling for the Betio wharf.

Local construction costs can be roughly approximated from the cost of the Bairiki Secretariat (figure 8) which amounted to $37,000. The cost factor probably is 2.5 to 3.0 times that of Washington, D. C.

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APPENDIX A

VEGETATION OF GILBERT ISLANDS

(Source: Atoll Research Bulletin No. 59, pages 79, 80.)

With the exception of *Pemphis* stands and, of course, of the mangrove proper, no primitive vegetation types can be recognized today. The original formations have been so thoroughly modified by man that there is no trace left of them, especially as all these islands are rather densely populated.

Besides the coconut palm, which covers the largest area, some species may still have a certain density and show marked preferences for some habitats, but they form a secondary vegetation rather than ruins of former original types.

In many cases the primary components are now represented only by isolated specimens, which tend to disappear not only because of the growing prevalence of the coconut palm but also because the natives do not care to preserve or propagate them. This is the case for trees such as *Pisonia*, *Cordia*, etc. In some islands even valuable trees such as pandanus may be disappearing, as they are considered of minor importance in comparison with the commercial value of copra.

The Gilbert Islands offer today the following vegetation types:

I. Vegetation of the seaward side

Scaevola, more or less dense, forms an almost unbroken belt. Their density is always greater than that of other neighbouring plants. This species grows nearest to the shore. *Messerschmidia* in isolated specimens or small groups are found, most of them with twisted trunks. Their height does not exceed 3 m. *Pandanus*, are more or less numerous, but always as isolated individuals. The prevailing low plants are: *Lepturus*, which is very seldom found in the shaded central zone, and *Fimbristylis*. A few *Triumfetta* and *Cyperus* sometimes grow among them. The *coconut palm* begins in this zone, the first rows growing a little above high-water mark.

II. Vegetation of the interior

The area occupied by other species is usually conditioned by the density of the coconut palms. If these are very close together, we find only the following low plants: *Thuarea*, *Fimbristylis*, *Euphorbia* and gramineae of the genera *Stenotaphrum* and *Cenchrus*, with a few small *Scaevola* here and there. If the coconuts are less dense, there will be some tree species such as: *Pandanus*, *Guettarda* and *Morinda*; and in addition to the low plants already mentioned, *Boerhavia*, *Triumfetta*, *Fleurya*, *Sida*, *Dodonaea* and *Cassytha*. The grasses are almost all present and *Psilotum* and *Polypodium* occur here and there at the foot of the coconut trees. Of course the number of these plants and the area they cover vary with the degree to which the ground is tended. If the coconut palms are very sparsely planted, some trees such as *Cordia* and *Pisonia* may occur, though rarely nowadays.

Many low plants survive with difficulty in open areas while species such as *Sida fallax*, which seem to prefer strong sunlight, can achieve great extension there.

III. Vegetation of the lagoon side (area of roads and villages)

The roadsides being generally cleared to a certain width, few plants are to be found there except common grasses. On the other hand, the shrubs and trees of the interior may be found again between the cleared road zone and the edge of the lagoon, with the addition of small groups of *Messerschmidia* forming a narrow strip slightly in front of the coconut palms.

One plant will be found growing densely on sandy areas that are always damp below the surface through tidal seepage; this is *Fimbristylis*, which tolerates high salinity. On the contrary, *Scaevola, Guettarda* and *Lepturus* always grow above the level of the highest tides.

Village areas offer a very different aspect, due to the number of plants cultivated in their immediate vicinity and around the houses. Among food trees, in addition to coconut palms which are widely spaced, breadfruit trees predominate, and sometimes reach a large size. Pandanus trees are found in varying numbers, mostly around the village periphery, except in the southern islands where they are given the same choice locations as *Artocarpus*. Papaya trees are found in every village and are often very tall. Banana plants are sometimes a component of this vegetation, but are grown only in pits. Small pumpkin patches are seen around the houses in southern islands, generally side by side with numerous tobacco plants, while *Ficus tinctoria* is usually found a little behind the last houses. Tomatoes and sweet potatoes are very scarce and we saw them only on a few islands in the centre and north of the Gilbert Group.

One of the characteristics of the Gilbertese village is the great variety of ornamental plants. The most commonly found are *Crinum, Russelia, Mirabilis, Catharanthus* and *Pseuderanthemum*. The low plants considered as weeds vary in abundance, of course, according to the cleanliness of the village and are, in fact, rather scarce. *Euphorbia prostrata, Fimbristylis, Phyllanthus, Eragrostis* and *Digitaria* are most often seen.

In addition to village and roadside vegetation, the *Pemphis* type should be given special mention. This shrubby plant (*Pemphis acidula* Forst) forms thick stands, often spreading over large areas, just at the limit of the highest tides of the lagoon, and above the first depressions filled by high tides and occupied by *Rhizophora*. The latter may often cover large areas which are submerged at high tide.

APPENDIX B

KEY PERSONNEL OF GILBERT AND ELLICE ISLANDS GOVERNMENT

Name	Position in August 1959	Temporary Rank	Permanent Position	Permanent Rank	Location
Bernacchi, M. L.	On leave	-	Resident Commissioner	1	Bairiki
Davies, R.	Acting Resident Commissioner	1	Secretary to Government	2	Bairiki
Turpin, R.	Acting Secretary to Government	2	Administrative Officer, Class B	-	Bairiki
Roberts, R. G.	District Commissioner, Gilbert and Ellice Islands	3	District Commissioner, Gilbert and Ellice Islands	3	Betio
Rees, W. H.	Acting Chief Medical Officer	4	Medical Officer	-	Bikenibeu
Shaw, J. A.	Acting Accountant General	5	Accountant	-	Bairiki

APPENDIX C

POPULATION OF GILBERT AND ELLICE ISLANDS COLONY

Table C-1. Breakdown of Population in Gilbert and Ellice Islands Colony. (Estimates as of 31 December 1958)

Location	Total	Native	Caucasian	Mongolian
GILBERT AND ELLICE ISLANDS DISTRICT:				
Makin	1,130	1,129	-	1
Butaritari	2,118	2,116	2	-
Marakei	1,790	1,787	3	-
Abaiang	3,234	3,226	8	-
Tarawa	7,125	6,982	141	2
Maiana	1,359	1,358	1	-
Abemama	1,341	1,334	7	-
Kuria	541	540	-	1
Aranuka	571	571	-	-
Nonouti	2,143	2,140	3	-
Tabiteuea	3,266	3,261	5	-
Beru	1,968	1,965	3	-
Onotoa	1,542	1,542	-	-
Nikunau	2,011	2,008	3	-
Tamana	1,142	1,142	-	-
Arorae	1,551	1,551	-	-
Subtotal for Gilbert Islands	*32,832*	*32,652*	*176*	*4*
Nanumea	928	928	-	-
Nanumanga	513	513	-	-
Niutao	731	731	-	-
Nui	485	485	-	-
Vaitupu	822	822	-	-
Nukufetau	579	579	-	-
Funafuti	567	562	5	-
Nukulaelae	270	270	-	-
Niulakita	43	43	-	-
Subtotal for Ellice Islands	*4,938*	*4,933*	*5*	*0*
Total for district	*37,770*	*37,585*	*181*	*4*
OCEAN ISLAND DISTRICT:				
Total for district	*2,381*	*2,135*	*170*	*76*
PHOENIX ISLANDS DISTRICT:				
Canton[a]	368	179	189[b]	-
Hull	729	729	-	-
Gardner	183	183	-	-
Total for district	*1,280*	*1,091*	*189[b]*	*0*
LINE ISLANDS DISTRICT:				
Washington	305	304[c]	1	-
Fanning	436	401[c]	34	1
Christmas[d]	374	373	1[d]	-
Total for district	*1,115*	*1,078*	*36*	*1*
GRAND TOTAL FOR COLONY	42,546	41,889	576	81

a - Condominium of United States and United Kingdom.
b - Caucasian population in June 1956.
c - Including a few "mixed race".
d - Excluding military forces.

Table C-2. Population Trends in Gilbert and Ellice Islands Colony.

Racial Segment	1931		1947		1958[a]	
	Number	Per Cent	Number	Per Cent	Number	Per Cent
Micronesians	28,946	85	29,923	83	36,956	87
Polynesians	3,668	11	5,006	14	4,933[b]	12
Mongolians	728	2	142	-	81	-
Caucasians	249	1	304	1	576	1
Mixed	231	1	565	2	?	
Total	33,822	100	35,940	100	42,546	100

a - Estimated by Government officials.
b - Total of Ellice Islands population, excluding 5 Caucasians.

APPENDIX D

SOME AVOIDANCES TO BE OBSERVED IN RELATIONS WITH NATIVES

(Source: Grimble, A. R. Instructions and Hints to District Officers. Suva: J. J. McHugh 1929.)

1. *Don't* expect to know the native until you have learned his home life. *Don't* expect to learn his home life except by constant hut-to-hut visitation. *Don't* expect to have any influence with the native until he knows that you know him.
2. *Don't* attempt to drive a native: lead him. *Don't* attempt to frighten him: he cannot be frightened physically.
3. *Don't* say anything that sounds like boasting or self-aggrandisement. There is a native proverb: "He owns no land, so his words are big."
4. *Don't* speak loud. There is another Gilbertese proverb: "A chief whispered: I swooned. A slave shouted: I awoke to laugh."
5. *Don't* reproach a native for bad manners until you are sure that you yourself are good-mannered according to his code.
6. *Don't* threaten or even speak of a native's head: it is sacred.
7. *Don't* point with extended finger: bend the finger and point with the knuckle.
8. *Don't* walk upright between two natives engaged in conversation. Bow the head, so as to clear their line of vision.
9. *Don't* forget to answer: "Te raoi" (peace!) if a native says "Ko raba" (thank you!).
10. *Don't* walk through a seated crowd without the preliminary courtesy: "E matauninga te aba?" (Are the people offended?). Say this and await the answer: "E aki matauninga, na rikai" (They are not offended, pass this way). Then proceed.

APPENDIX E

COMMUNICATIONS IN GILBERT AND ELLICE ISLANDS COLONY

The communications network in the Gilbert and Ellice Islands Colony consists of 34 stations, listed in table E-1. Regular contacts also are maintained with several other communications points outside the colony.

Communications equipment at Tarawa, which is the Government center of the colony, includes the transmitters detailed in table E-2, the receivers detailed in table E-3, and the VHF transmitter-receiver system described in table E-4. The test equipment at Tarawa, used to keep the communications equipment in good operating condition, is listed in table E-5.

The communications operations at Tarawa can be classified as point-to-point communications, shore/ship communications, ground/air communications, aircraft navigational aid, and local broadcasting service. The usage of equipment at Tarawa in these operations is described in tables E-6, E-7, and E-8.

The layout of receiving/operating positions, the staffing of receiving and transmitting stations, the stocking of spare units, and the maintenance of equipment at Tarawa are all simplified by an arrangement in which certain individual equipments are used at different times for different circuits, usually but not necessarily on the same frequencies. This arrangement is shown by the Tarawa radio schedules for 1 September 1959 detailed in table E-9. Although some circuits appear to be inadequately provided with night or secondary frequencies, local officials say that doubtless allocations would be available if the necessity arose or if the period of service were extended from the present 18 hours per day to 24 hours per day.

The normal working frequency for shore/ship communications is 4108.4 kilocycles, and the alternate frequency is 6282 kilocycles (which is limited to CW). The Pacific area small ships distress frequency is 2182 kilocycles. It should be noted that the Colony ships are not equipped to use the international distress frequency of 500 kilocycles.

Broadcasting in vernacular is limited at present to 1 hour per week on the frequency of 6050 kilocycles. One of the communications transmitters (radiating 200 watts) is borrowed for these broadcasts. The programs are tape recorded by the Information Office personnel at Bairiki, who have audio facilities and a Ferrograph (English) tape recorder. The taped programs are fed into the transmitter on Sundays from 1640M to 1715M (local time). The programs, which are half Gilbertese and half Ellice, include reports of colony news and local music. Although the reception is limited to the Gilbert and Ellice groups, reports are usually favorable. There are not very many private radio receivers outside Tarawa, but community listening is popular.

Broadcasting in English is scheduled for 2 hours per week on the frequency of 844 kilocycles. The program is broadcast by use of locally constructed studio equipment and a locally constructed low-power transmitter. The programs, which consist of local news reports, music, and British Broadcasting Corporation feature transcriptions, are presented on Fridays from 1930M to 2130M (local time). This low-power broadcasting station is located near the transmitting station for colony communications.

At the end of 1959, a new 2.5-kilowatt transmitter is being installed in the transmitting station, a remote studio is being installed on Betio, and another studio is being installed in the Information Office at Bairiki. This transmitter equipment, which is manufactured by Standard Telephones and Cables, Ltd. (Australian), will require a 3-phase AC power input. The associated audio equipment to be used in the remote studios is mostly manufactured by Amalgamated Wireless Austrasia, Ltd. (Australian) and PYE (English). A special high-angle radiation antenna, termed a vertical incidence array, will be used with this new transmitter. The radiation will be limited to the Gilbert and Ellice Islands, but a reliable service area is anticipated.

When this new broadcasting equipment is put into operation, the vernacular programs probably will continue to be recorded in most instances, but under better conditions. However, live programs from the new remote studio on Betio will be possible.

Although the studio equipment probably will be used to produce live programs for the English broadcasts, it is not proposed at present to use the new transmitter for the English service. Probably, the low-power transmitter will be moved to the transmitting station and the small building which now houses the low-power transmitter will be demolished.

Table E-1. Wireless Stations in Gilbert and Ellice Islands Colony. (Total of 34 Stations in Colony)

Station	Call Sign
Gilbert Islands (19 Stations):	
Headquarters, Tarawa	VSZ
Bairiki, Tarawa	VSZ 39
Bikenibeu, Tarawa	VSZ 40
Abaokoro, Tarawa	VSZ 38
Makin	VSZ 35
Butaritari	VSZ 32
Marakei	VSZ 34
Abaiang	VSZ 33
Maiana	VSZ 37
Abemama	VSZ 36
Kuria	VSZ 25
Aranuka	VSZ 26
Nonouti	VSZ 24
Tabiteuea	VSZ 23
Beru	VSZ 27
Onotoa	VSZ 29
Tamana	VSZ 30
Arorae	VSZ 31
Nikunau	VSZ 28
Ellice Islands (9 Stations):	
Nanumea	ZJU 22
Nanumanga	ZJU 27
Niutao	ZJU 24
Nui	ZJU 23
Funafuti	ZJU
Vaitupu	ZJU 25
Nukufetau	ZJU 28
Nukulaelae	ZJU 29
Niulakita	ZJU 26
Ocean Island (1 Station):	VQK
Phoenix Islands (3 Stations):	
Canton	ZIT
Hull	ZIT 23
Gardner	ZIT 25
Line Islands (2 Stations):	
Fanning	VQN 22
Christmas	VQN 23

Table E-2. Summary of Available Information on Transmitters at Tarawa.

Number On Hand	Type or Model	Manufacturer	Source	Input Power Required	Unmodulated Output Power to Antenna (Watts)	Antenna	Frequency Range		Usage
							(Megacycles)	(Kilocycles)	
2	AT14	T and S (Australian)	Purchased after World War II from Australian Air Force (wartime model)	240 volts AC 1-phase mains-operated	200	Hertz*	2 - 20	--	CW, MCW, voice
2	AT13	AWA (Australian)	Purchased in 1946 from Australian Air Force (wartime model)	--	200	Hertz*	2.5 - 20	--	MCW
1	12J50904	AWA (Australian)	Purchased in 1947 (postwar model)	--	500	Terminated "V", directed at Fiji; 600-ohm twin feeder	2 - 20	--	CW, MCW, voice
1	1J51020	AWA (Australian)	Purchased in 1947 (postwar model)	240 volts AC 1-phase mains-operated	100	Long wire, horizontal	2 - 20	330 - 520	CW, MCW, voice, navigational aid**
1	--	Local engineers	Constructed at Tarawa in 1950	--	50	Top-loaded long wire, horizontal	--	844	Voice***
1	--	STC (Australian)	Being installed at end of 1959	AC 3-phase	2,500	Vertical incidence array (special high-angle radiation)	--	--	Voice****

T and S = Thom and Smith, Ltd.
AWA = Amalgamated Wireless Australasia, Ltd.
STC = Standard Telephones and Cables, Ltd.

*Single-element, simple half-wave, horizontal Hertz antenna; delta-matched by a 600-ohm twin feeder and cut to proper length for the frequency used.

**Fitted with separate automatic keying unit, constructed at Tarawa, to transmit long dashes interspersed with identification "TW" as a navigational aid to aircraft in the Tarawa region.

***Used with locally constructed studio equipment.

****To be used with audio equipment manufactured by AWA (Australian) and PYE (English) and located in remote studios at Betio and at the Information Office at Bairiki.

Table E-3. Summary of Available Information on Receivers at Tarawa

Number On Hand	Type or Model	Manufacturer	Source	Components	Input Power Required	Antenna	Usage
5	AMR type 680X	Eddystone (English)	--	13 tubes, a rectifier, and voltage stabilizer	240 volts AC mains-operated	Hertz doublet, shielded feed	MCW
1	AMR type C13500	AWA (Australian)	Purchased from wartime disposals	9 tubes and rectifier	240 volts AC mains-operated	Hertz doublet, shielded feed	CW
1	type RA-1B	Bendix (American)	Purchased from wartime disposals	8 tubes and rectifier	240 volts AC mains-operated	Long wire, horizontal	CW, MCW

AWA = Amalgamated Wireless Austrasia, Ltd.

Table E-4. Summary of Available Information on Transmitter-Receiver at Tarawa

Number On Hand	Type or Model	Manufacturer	Input Power Required	Unmodulated Output Power to Antenna (Watts)	Antenna	Frequency Used (Megacycles)	Usage
1	FM type 30 SU 8C	Standard Telephones and Cables, Ltd. (Australian)	240 volts AC mains-operated	10	Ground plane mounted on mast 80 feet above surface of ground	74*	VHF FM voice**

* Same frequency used for both transmitting and receiving.

** Fitted with operator's control unit for two extensions at Betio, one to the public telephone booth at the Receiver Station and the other one to the District Office.

Table E-5. Test Equipment Used in Radio Workshop at Tarawa

Quantity	Equipment	Type or Model	Manufacturer	Testing Range
2	Multimeter	Model 8 Universal	Avo (English)	- -
1	Multimeter	University type MVA/2	- - (Australian)	- -
1	Insulation tester	Series 3	Megger (English)	- -
1	Signal generator	Type E2	Advance (English)	100 - 100,000 kilocycles
1	Signal generator	Type A51948	AWA* (Australian)	VHF (fixed frequency)
1	Audio oscillator	RC generator GM 2315/02	Philips (Dutch)	20 - 20,000 cycles per second
1	Oscilloscope	GM 5655/02	Philips (Dutch)	- -
1	Measuring bridge	Philoscop 11 type GM 4144/01	Philips (Dutch)	- -
1	Valve voltmeter	Electronic testmeter Mk 4	Avo (English)	- -
1	Valve tester	Type 160	Avo (English)	- -
1	Testmeter	- -	STC** (Australian)	VHF
1	Neutralizing meter	(for AWA transmitters)	AWA* (Australian)	- -
1	Frequency meter	Model BC221-M	Bendix (American)	125 - 20,000 kilocycles

* Amalgamated Wireless Austrasia, Ltd.

** Standard Telephones and Cables, Ltd.

Table E-6. Equipment Usage at Tarawa in Point-to-Point Communications.

Station		Type of Signal	Transmission			Reception		
Location	Call Sign		Type of Transmitter	Frequency (Megacycles)		Type of Receiver	Frequency (Megacycles)	
				Day	Night		Day	Night
Gilbert Outer Islands	VSZ + suffix	MCW	AT14*	6.9875	--	C13500	7.460	3.730
Ellice Islands	ZJU + suffix	MCW	AT14*	6.9875	--	C13500	7.460	3.730
Ocean Island	VQK	MCW	AT13**	11	--	680X	7.490	--
Phoenix Islands	ZIT + suffix	MCW	AT13**	11	--	680X	9.825	--
Line Islands	VQN + suffix	MCW	AT14*	6.9875	6.9875	C13500	7.460	3.730
Suva	VPD	MCW	AT13**	11	--	680X	13.395	5.800
Honiara	VQJ	MCW	AT13**	11	--	680X	11.568	--
Nauru	VKT	MCW	AT13**	11	--	680X	8.175	8.175
Nadi	ZQD	MCW	AT13**	11	11	680X	11.450	9.400
Nadi	ZQD	MCW	12J50904	16.0775	--	680X	15.600	--
Bairiki***	VSZ	VHF FM voice	30-SU-8C	74	74	30-SU-8C	74	74
Bikenibeu***	VSZ	VHF FM voice	30-SU-8C	74	74	30-SU-8C	74	74

* Same transmitter.
** Same transmitter.
*** Intra-Tarawa communications.

Table E-7. Equipment Usage at Tarawa in Shore/Ship Communications

Station	Type of Signal	Transmission			Reception		
		Type of Transmitter	Frequency (Kilocycles)		Type of Receiver	Frequency (Kilocycles)	
			Day	Night		Day	Night
Colony ships, overseas ships in area, or as required	MCW, voice	AT14	8790.2 4413.8	- - 4413.8			
	CW, voice				680X	4108.4 2182	4108.4 2182
	CW				680X	6282	6282
Overseas ships (international distress frequencies)	CW, MCW	1J51020	500 422 410	500 422 410	RA-1B	500 422 410	500 422 410

Table E-8. Equipment Usage at Tarawa in Ground/Air Communications, Aircraft Navigational Aid, and Local Broadcasting Service

Station	Type of Signal	Transmission			Reception		
		Type of Transmitter	Frequency (Kilocycles)		Type of Receiver	Frequency (Kilocycles)	
			Day	Night		Day	Night
Ground/air: All aircraft in area	MCW, voice	AT14 or 1J51020	13344.5 8845.5	5641.5 2945	680X	13344.5 8845.5	5641.5 2945
Navigational Aid: All aircraft in area as required	CW*	1J51020	375	375			
Local Broadcasting: Gilbert and Ellice Islands	Voice**	AT14	6050	6050			
Tarawa	Voice***	Local****	844	844			

* Automatically keyed to send long dashes interspersed with identification "TW."

** Vernacular programs.

*** English-language programs.

**** Constructed by local engineers for low-power (50 watts) operation.

Table E-9. Tarawa Radio Schedules as of 1 September 1959

Time		Type of Schedule *	Station	Frequency Used by Tarawa (Kilocycles)	
Local (M Zone)	Greenwich Mean			Transmission	Reception
0600	1800	C	Open VHF, local, and overseas shipping watches	74000 4113 500	74000 4108 500
0600	1800	WX	ZJU 22, 23, and 26; VSZ 27, 31, and 32	6987.5	7460 3730
0600	1800	WX	VQK Ocean Island	11000	7490 3745
0600	1800	C	Special schedule for Bairiki, Bikenibeu (priority only) VHF	74000	74000
0615	1815	C	ZJU Ellice subs	6987.5	7460 3730
0620	1820	WX	ZQD Nadi	11000 16077.5	9400 11450
0700	1900	C	VSZ send traffic list and traffic to Ellice subs	6987.5	7460 3730
0705	1905	WX	ZQD Nadi if no contact at 0620M	11000	15600
0730	1930	C	ZPD Suva	11000	13395
0800	2000	C	Watch-keeping this area until 1000M		500
0800	2000	C	Colony shipping	4413.8	4108.4
0800	2000	C	Bairiki and Bikenibeu worked on 6987.5 kilocycles when ZJU Ellice clear (until 0845M), then VSZ changes to 4413.8 kilocycles. Bairiki and Bikenibeu keep continuous watch on VHF during office hours.	6987.5 4413.8	3502.5 74000
0830	2030	C	Bairiki, Bikenibeu Sundays and holidays only	4413.8	3502.5

* C Commercial communications
WX Weather information

Table E-9. Tarawa Radio Schedules (Cont'd)

Time		Type of Schedule*	Station	Frequency Used by Tarawa (Kilocycles)	
Local (M Zone)	Greenwich Mean			Transmission	Reception
0855	2055	WX	VQK Ocean Island, ZJU Funafuti, VSZ 31 Arorae	6987.5	7460
			VQK Ocean Island		7490
0900	2100	C	VQK Ocean Island listens on 11000 kilocycles until 1000M	11000	7490
0900	2100	WX	ZQD Nadi	11000	15600
0900	2100	C	VSZ sends shipping notes and traffic list to Northern Gilberts, sends and receives traffic until 1015M	6987.5	7460
0905	2105	C	ZIT Canton listens for VSZ on 11000 kilocycles until 1000M (Pass priority Government and all private traffic for Christmas)	11000	9825
0915	2115	C	VPD Suva	11000	13395
0950	2150	C	VQJ Honiara (Sundays, holidays only priority traffic)	11000	11568
1015	2215	C	VSZ sends shipping notes and traffic list to Southern Gilberts, handles traffic until 1130M	6987.5	7460
1015	2215	WX	ZQD Nadi administration	11000	15600
1030	2230	C	VKT Nauru	11000	8175
1050	2250	C	VQJ Honiara (except Sundays and holidays)	11000	11568

* C Commercial communications
WX Weather information

Table E-9. Tarawa Radio Schedules (Cont'd)

Time		Type of Schedule*	Station	Frequency Used by Tarawa (Kilocycles)	
Local (M Zone)	Greenwich Mean			Transmission	Reception
1100	2300	C	VQK Ocean Island listens for VSZ until 1200M (except Sundays)	11000	7490
1130	2330	C	VPD Suva	11000	13395
1130	2330	C	VSZ 31 Arorae accepts priority traffic for Ellice weather subs	6987.5	7460
1150	2350	WX	VSZ 31 Arorae passes Ellice weather to Tarawa	6987.5	7460
1155	2355	WX	VSZ 32 Butaritari	6987.5	7460
1200	2400	C	Bairiki, Bikenibeu Sundays and holidays	4413.8	3502.5
1200	2400	WX	VQK Ocean Island	11000	7490
1200	2400	C	Watch-keeping this area until 1400M		500
1200	2400	C	Tarawa sends traffic list and exchanges traffic with Northern Gilberts until 1445M	6987.5	7460
1205	0005	WX	ZQD Nadi	16077	15600
1300	0100	C	Tarawa keeps special schedule Colony ships (urgent traffic only)	4413.8	4108.4
1305	0105	WX	ZQD Nadi for area forecast	16077	15600
1400	0200	C	VKT Nauru (except Saturdays, Sundays, and holidays)	11000	8175
1445	0245	C	ZIT Canton keeps watch on Tarawa for traffic until 1545M	11000	9825

*C Commercial communications
WX Weather information

Table E-9. Tarawa Radio Schedules (Cont'd)

Time		Type of Schedule*	Station	Frequency Used by Tarawa (Kilocycles)	
Local (M Zone)	Greenwich Mean			Transmission	Reception
1445	0245	C	Tarawa works VQK on 6987.5 kilocycles until weather is collected at 1445M (except Sundays)	6987.5	7490
1455	0255	WX	Tarawa collects weather from Ocean, Funafuti, and Arorae	6987.5	7460
			VQK Ocean Island		7490
1500	0300	C	Tarawa sends traffic list and subs, receives traffic from Southern Gilberts until 1730M	6987.5	7460
1500	0300	C	VQK Ocean Island keeps listening watch on Tarawa for traffic until 1600M (except Sundays)	11000	7490
1510	0315	WX	ZQD Nadi	16077	15600
1530	0330	C	VPD Suva	11000	13395
1600	0400	C	Tarawa works Colony shipping	4413.8	4108.4
1600	0400	C	Watch-keeping this area until 1800M		500
1600	0400	C	VQJ Honiara (except Saturdays, Sundays, and holidays)	11000	11568
1630	0430	C	Bairiki, Bikenibeu	4413.8	3502.5
1645	0445	WX	VQD Nadi administration (except Sundays)	11000	15600
1700	0500	C	VQK Ocean Island keeps watch on Tarawa until 1800M	11000	7490
1730	0530	C	VPD Suva	11000	13395

*C Commercial communications
WX Weather information

Table E-9. Tarawa Radio Schedules (Cont'd)

Time		Type of Schedule*	Station	Frequency Used by Tarawa (Kilocycles)	
Local (M Zone)	Greenwich Mean			Transmission	Reception
1800	0600	WX	Collection of subs weather until 1800M	6987.5	7460 3730
1800	0600	C	Special VHF schedule with Bairiki and Bikeni-beu (urgent or priority traffic only)	74000	74000
1820	0620	WX	ZQD Nadi	11000	9400
1830	0630	C	VQN 23 Christmas Island	6987.5	7460 3730
1830	0630	C	ZIT Canton Island keeps listening watch for traffic until 1930M	11000	9825 7460
1900	0700	C	VPD Suva	11000	13395
1930	0730	C	ZJU Funafuti	6987.5	7460 3730
1945	0745	C	VKT Nauru (except Saturdays, Sundays, and holidays)	4413.8	8175
2000	0800	C	Watch-keeping this area until 2200M		500
2000	0800	C	Special VHF schedule with Bairiki and Bikeni-beu (urgent or priority traffic only)	74000	74000
2000	0800	C	VQK Ocean Island keeps listening watch until 2200M	11000 6987.5	7490 3745
2200	1000	C	Special VHF schedule with Bairiki and Bikeni-beu (urgent or priority traffic only)	74000	74000
2340	1140	WX	ZJU 26 Niulakita	6987.5	7460 3730

* C Commercial communications
WX Weather information

Table E-9. Tarawa Radio Schedules (Cont'd)

Time		Type of Schedule*	Station	Frequency Used by Tarawa (Kilocycles)	
Local (M Zone)	Greenwich Mean			Transmission	Reception
2345	1145	WX	Collection of weather from subs, including ZIT 25 Gardner Island	6987.5	7460 3730
2345	1145	WX	Collection of weather from VQK Ocean Island	6987.5	7490 3745
2400	1200	WX	ZQD Nadi	4413.8	9400

* C Commercial communications
WX Weather information

ATOLL RESEARCH BULLETIN

No. 73

Some aspects of agriculture on Tarawa Atoll, Gilbert Islands

by

R. R. Mason

Issued by

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Washington, D. C.

October 15, 1960

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DIAGRAMS

Some aspects of agriculture on Tarawa Atoll,

Gilbert Islands

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R. R. Mason

INTRODUCTION

The following paper is part of a report written in 1951 which has not previously been published. The writer spent three months on Tarawa taking part in the South Pacific Commission's project E.6, the economic development of coral atolls. The report of Dr. R. Catala,* the leader of the S.P.C. team, has been published (Atoll Res. Bull. 59: 1957).

It had been intended to visit two or three other islands after completing investigations on Tarawa; but shortage of transport made it necessary to return to Fiji when an opportunity offered, before any other islands could be visited.

Work accomplished includes soil and water investigations, studies on the main crops* (coconuts, Cyrtosperma, pandanus, etc.), observations on livestock, and some brief notes on tools and on native plants.* Consideration was given to the establishment of a small agricultural station at Bikenibeu, near the site chosen for the King George V school.

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* The published report by Dr. Catala incorporated parts of the observations made on Tarawa by Mr. Mason and treated some of the same subjects. To avoid costly duplication of material, some chapters of Mr. Mason's report are omitted from this Bulletin. The report of Dr. Catala also contains many photos which illustrate points brought out by Mr. Mason.--Ed.

SOILS OF TARAWA

Since all the soils of Tarawa Atoll are derived from coral, there is no great variation. Hard coral rock outcrops in a few places, and in others there is little or no sand but many stones--for example, at Temaiku. In general, however, there is a layer of sand two to six feet deep above the underlying coral rock. Where soil has been developed, the commonest profile is a horizon of brown to dark brown sandy material high in organic matter and from 2 to 12 inches deep, overlying a pale brown horizon extending to between 12 and 30 inches; below this is coarse yellowish-white sand. This soil type has been named the Bikenibeu Sand ("B"); 17 profiles were examined and some are described below.

Two phases of this soil type were met fairly frequently. They are the Bikenibeu Sand Shallow Phase ("Bsh"), in which hard coral rock is found at 36 inches or less; and the Bikenibeu Sand Stony Phase ("Bst"), with a stony layer, often closely packed, usually at about twelve inches. Nine profiles of these two phases were examined.

The Eita Marine Marsh ("E") is a soil type in which extreme salinity inhibits plant growth. The type occurs infrequently in depressions behind the ocean and lagoon beaches.

The Mweang skeletal soil ("M") shows a dark-brown or black peaty sand in the upper layers, associated with large numbers of small stones, the soil occupying the interstices between the stones. Three profiles were examined, in separate areas. The dark-coloured soil, if sieved free from stones, is useful for gardening.

The fourth soil type is the Te Ribu loamy sand ("R"), which again was found in small isolated areas. The loamy sand characteristic of this soil type is found at a variable depth, never on the surface, although at Buota it was uncovered at the bottom of 'babai' pits. It is sufficiently plastic to be moulded in the fingers. This soil appears to be very poor, for the coconuts at Buota were few in number and were yellow with little fruit, and there was no grass. In the pits the 'babai' was poor and yellowish except for a few plants growing in a shaded place. Shade however was very limited. A similar condition, though not so pronounced, was seen near Buariki.

The rapid variation of soil type and the consequent impracticability of preparing soil maps is shown by figure 1, a plan giving the different types in the Bikenibeu area.

Apart from the exceptions mentioned above, there was little correlation between soil type and plant growth. No correlation was observed between production of coconuts and depth of dark soil except when the latter was less than two inches. On the other hand, profile No. 4 was from an area where the trees were distinctly above average, and it showed the horizons at 4 and 8 inches only, with maximum root development between 12 and 18 inches. The only places where fertility was markedly higher were on a deep dark-coloured soil at Buariki, where the rainfall is probably a little higher, and on Betio. Pre-war Betio is said to have been no different from the other islets, but now the difference is great.

A young coconut, not more than 5 years old but already starting to flower was typical of many. The creeper Ipomea pes-caprae was running riot in places. The increased fertility is the result of the intense disturbance of the ground by bombs and shells in 1944, and of the many thousands of Japanese buried there. Many plants not seen elsewhere flourish there despite the lack of shade. As a result of the bombardment, there were only about twenty mature coconut trees left on the whole islet after the war.

The underlying coral rock was not often reached in digging pits, but was quite frequently seen in village wells. (Profiles could not be taken since the sides are built up with stone). A very hard layer was reached in Well No. II at Bikenibeu at 99 inches. This appeared to be very thick, although several wells were seen where it was only 3 to 4 inches. Its porosity was shown by the water rising through it with the rising tide. A series of borings with a post-hold borer showed the varying depths in a cross section of the island east of the village of Bikenibeu. The rock is prominent at that place on both the lagoon and ocean shores. On the lagoon side of the island ('Tanrio') the depth was about 3 feet near to the road, twenty yards from the sea. Trees were bearing fairly well in all three places. Presumably the root system was sufficiently long to reach the deeper soil. (Many roots were encountered while digging well No. IV at Bikenibeu although no trees grew within 10 yards.)

Outcrops of rock occur near Eita village and on the small peninsula at Temaiku. No coconuts grew in the former place; but in the latter, fruit was produced to a limited extent even where there was 4 inches or less of sand over the rock. Presumably cracks exist. East of Abatao is an area of fairly hard stone, but a pit showed extensive coconut roots underneath, at 6 to 10 inches depth. This is not coral but appears to be a type of mudstone which has hardened on exposure.

Soil samples collected in Tarawa and despatched to Suva for analysis were all ruined by sea water while in the hold of R.C.S. "Kiakia," together with most of the entomological specimens. The following ten analyses were made in Tarawa, using the 'La Motte' apparatus. (Table 1, p.4)

These samples were taken where the soil by its blackness or the coconuts by their fruit appeared above average.

Native names for different kinds of sand and soil are as follows:

Te Bike	Shore sand
Te Tano	Ordinary sandy soil
Te Bon, Te Bon Ro, Te Iarauri	Black soil, frequently found under 'Te Uri' (Guettarda)
Te Mweang	Light black soil which blows in the wind.
Te Ribu, Te Riburibu	Grey clayey soil. Worse than sand if water is salty.
Te Ririba	Outcrops of rock
Te Bokaboka	Mud in babai pits etc.

TABLE NO. 1

Soil Type	Profile No.	Depth in inches	Soil description	p H	Nitrate Nitrogen (p.p.m.)	K m.e per 100 gms	P_2O_5
M	29	0-12	Black peaty soil between stones	7.6	4	3.0	0.023
M	30	0-6	Representative sample of area	8.0	12	3.0	0.020
R	32	1-3	Brown, very sandy	8.2		2.5	0.003
	"	20-24	Dark brown former surface				
	"	60	Grey, clayey, slightly sticky	7.8			
B	8	0-8	Black, high organic matter	8.0		2.5	0.011
	"	8-18	Dark, less organic matter	8.2			
	"	84	Whitish coarse sand	8.2			
B	8	0-6	Representative sample of area	8.0	6	2.7	0.017
B	6	0-6	Dark brown sand	8.0	30	3.0	0.009

* Author did not state what units the $P_2 O_5$ figures represent.--Ed.

Description of Soil Profiles

Soil types:	Bikenibeu sand		B
	Bikenibeu sand	Shallow phase	BsL
	Bikenibeu sand	Stony phase	Bst
	Eita marine marsh		E
	Te Mweang		M
	Te Ripu		R

No structure was observed in any of these soil types.

BIKENIBEU SAND (B)

Profile No. 6: Tabaongo, $1\frac{1}{4}$ miles east of Bikenibeu wells

Surface: Coconuts with patches of Lepturus

1.	0 to 2 inches	Dark brown sand, friable, organic-matter-stained, free draining, few roots, no stones.
2.	2 to 54 inches	Pale brown sand, loose, no organic matter free draining, root development greatest between 6 and 18 inches with some to 36 inches. No stones.
3.	54 to 69 inches	Pale yellow sand, loose, no organic matter free draining, no roots, coral fragments up to 2 inches in size.
4.	69 + inches	Hard coral rock. Water rises to 66 inches at high water only.

This is the commonest type of profile. Considerable variation occurs in the extent of the horizons. Horizon I sometimes extends to 5 inches, while horizon 3 was sometimes met as high as 10 inches. Less developed profiles occur particularly near the beaches. Occasionally a buried former surface is met. In places where the coral rock was not reached by about 6 feet, further digging was prevented by water.

BIKENIBEU SAND, SHALLOW PHASE
(B sL)
Profile No. 18

Surface: Coconut palms, germinating nuts; fallen leaves, no grass.

1.	0 to 10 inches	Brown sand, friable, organic-matter stained, free draining. Maximum root growth between 3 and 9 inches. No stones.
2.	10 to 20 inches	Yellow coarse sand, loose, no organic-matter, free draining. Few roots, no stones.
3.	20 + inches	Hard coral rock.

In other profiles horizon 1 varies from 2 to 12 inches and from brown to dark brown. In the other pits examined, the hard coral was struck at depths between 27 and 38 inches. It was too hard to be broken by crow-bar.

BIKENIBEU SAND, STONY PHASE
(B st)

Profile No. 25, 3/4 mile east of Bikenibeu.

Surface: Coconut palms rather yellow, yield fair to poor. No other vegetation.

1.	0 to 2 inches	Brown sand, friable, organic-matter stained, free draining, few roots, no stones.
2.	2 to 15 inches	Pale grey-brown sand, loose, no organic-matter, free draining, root development throughout; no stones.
3.	15 + inches	Stones - irregular flat coral stones lying horizontally and too tightly packed to prise with spade without great difficulty.

The thickness of the stony layer is variable. In profile 26, at the old site of Eita village, a layer of flat very hard white smooth coral stones up to 12 inches long and $1\frac{1}{2}$ inches thick occurs between 14 and 16 inches. Below this occurs a horizon of yellow and brown very coarse sand with few roots but with many stones.

EITA MARINE MARSH
(E)

Profile No. 27: salt bog 22 yards inland from ocean beach, with high sand bank intervening. Due south of Te Bike island.

Surface: bare of vegetation; greenish-brown in colour.

1.	0 to 3 inches	Pale grey sand
2.	0 to 10 inches	Grey sand
3.	10 +	Yellow coarse sand

Brackish water was struck at 7 inches but later it rose to 1 inch, and probably covers the surface at high water spring tides. Salt content very high - approximately 1.98% chloride. Typical of numbers of small isolated areas close to the sea where fluctuations of salty water associated with tidal rise and fall inhibits growth of vegetation.

TE MWEANG
(M)

Profile No. 28, south of Taborio village.

Surface: Vegetation cover of coconuts, sparse *Lepturus*, and some shrubs. Ground surface comprises white coral pebbles.

1.	0 to 14+inches	Black highly organic sand occupying the interstices between the closely packed stones, free draining, roots throughout, extremely stony.

The highly-packed stones make digging almost impossible. One pit near Abatao, however, penetrated the upper horizons and reached off-white sand with many larger stones at 18 inches.

It would appear that the reason for the striking accumulation of organic matter in this soil type is that all root growth is confined to the very small volume of soil between the stones; thus the continuing addition of organic matter to the soil balances the losses through oxidation.

TE RIPU
(R)

Profile No. 32: near Buota

Surface: Coconuts unhealthy in appearance, yellowish and with few nuts. No grass cover. Cyperus, Sida, Pandanus, Scaevola occur close by, Guettarda scrub being dominant at this spot.

1.	0 to 10 inches	Dark, nearly black loamy sand, friable, organic-matter stained, few roots, no stones.
2.	10 to 30 inches	Grey fine sandy loam, slightly sticky when wet, no organic matter, no roots, no stones.
3.	30 + inches	Mixed coral fragments.

WATER

Water is very frequently the limiting factor for growth. The rainfall is extraordinarily variable.* In 1930, 138.52 inches fell, 29 inches being in November. (These figures are by courtesy of the New Zealand Meteorological Service and the Gilbert and Ellice Administration.) In 1950 a total of 15.38 inches fell in twelve months - 2.94 inches in the first seven months. (Rainfall is high in the northern islands and lower in the south; in 1950 Beru, one of the southern islands, received 9.68 inches.) The mean for Tarawa over 16 years is 64.19 inches per annum. Naturally last year's drought (1950) killed off numbers of coconuts in poor environments such as on sand spits or on small islands. It seems remarkable that anything could stay alive.

Ground-water can be obtained anywhere that a hole can be dug to a depth of from five to ten feet, depending on the height of the land. Drinking water is obtained from wells of low salinity. It appears that the level of well water varies only slightly with conditions of rainfall but no definite data could be obtained on this subject. (A recording device was designed but was not completed before leaving.) There is a very pronounced rise and fall of ground-water due to the effect of the tides. Naturally the movement is greatest close to the beach and least in the centre of the island. Nine wells were dug at Bikenibeu on a line at right angles to the beaches, to give a transverse section of the land, and the levels in these were recorded over a 36 hour period. Graphs from the data obtained are shown in Figure 2. Since all nine could not be plotted on the same axes, the first five and the last four are given separately. The sites of the wells are shown in Figure 3; well No. 1 is nearest to the ocean beach, and well No. 9 is on the lagoon tidal sand flats. The graphs are plotted about a common mean, and show clearly how the movement decreased from No. 1 to No. 5 and increases again from No. 6 to No. 9 though with less regularity. It is also clearly shown

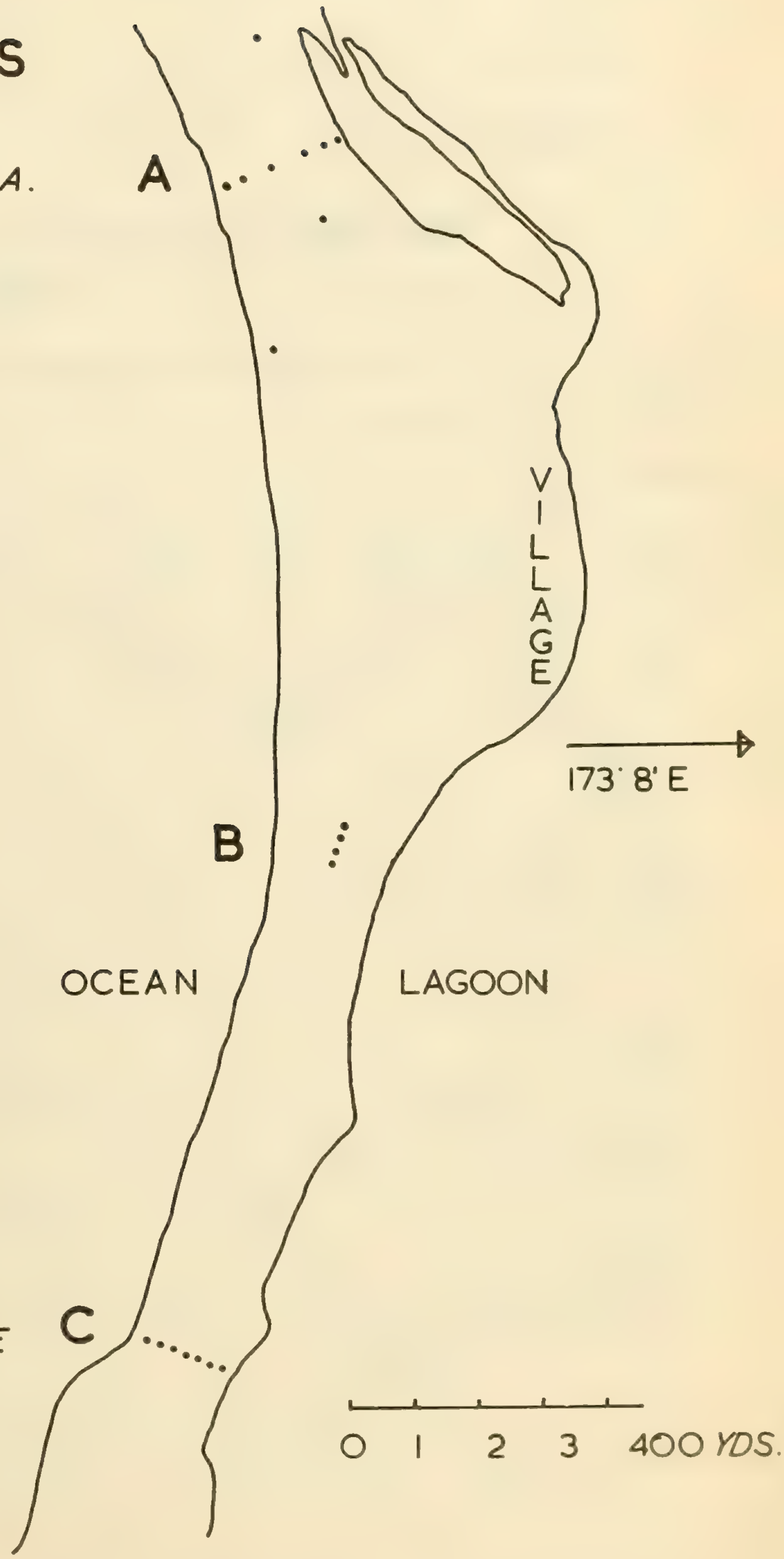
* Rainfall tables are included in Atoll Res. Bull. 60: 1957, by M.-H. Sachet.--Ed.

FIGURE NO. 1

SOIL TYPES

IN THE

BIKENIBEU AREA.



A

			B 8		
B 3	B 2	BS 23	R 34	R 33	B 1
B 4			R 32		

B

B 24
R 30
BS 25
B 5

C

BSH 19	BSH 20	BSH 21	B 6	B 7	BSH 22

B : *BIKENIBEU SAND*
BS : ,, ,, *STONEY PHASE*
BSH : ,, ,, *SHALLOW PHASE*
R : *TE RIPU CLAYEY SAND*

NUMBERS REFER TO PROFILES.

FIGURE No. 2

WATER LEVELS IN THE BIKENIBEU WELLS

RECORDED IN INCHES OVER A 36 HOUR PERIOD.

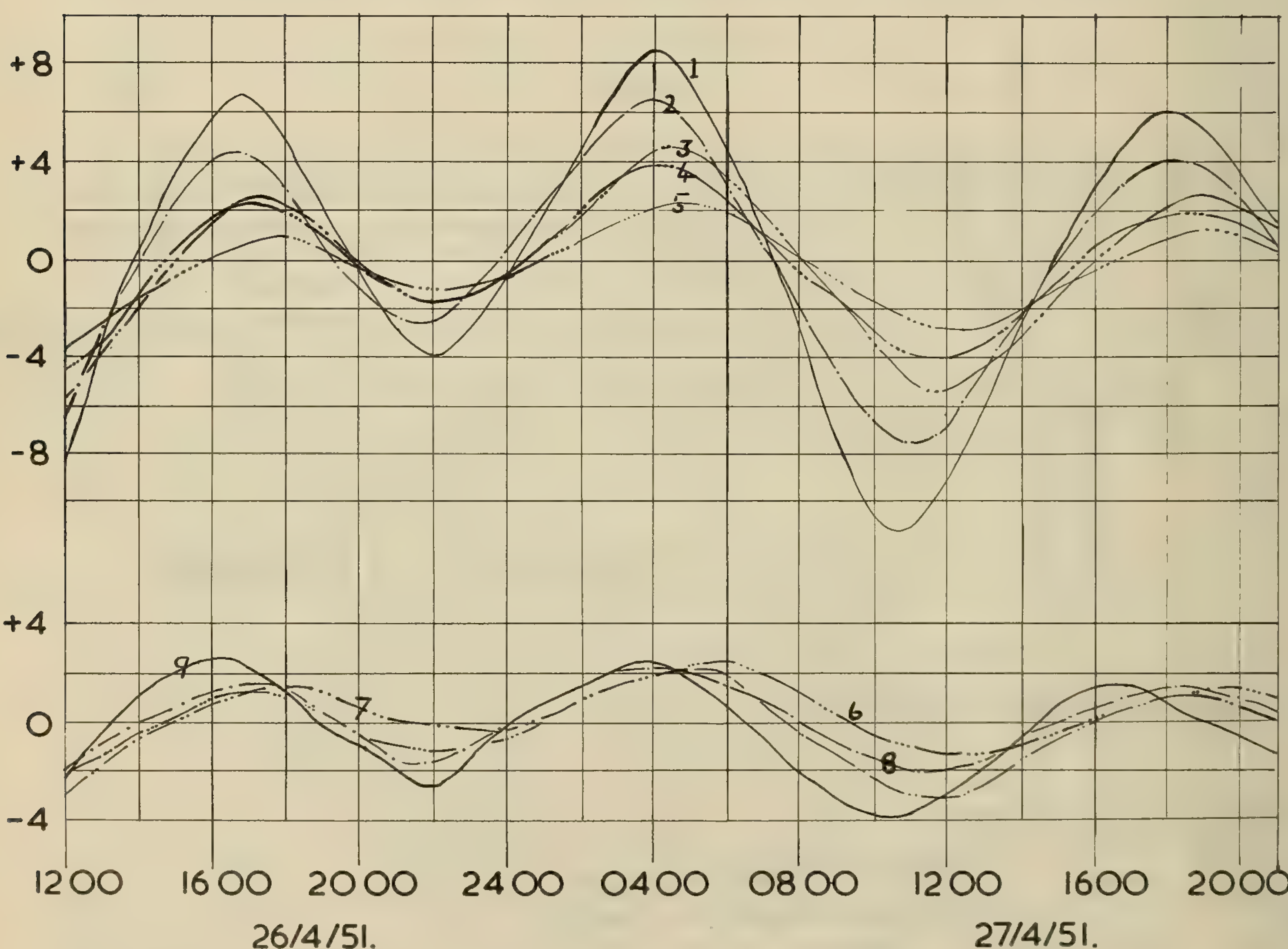


FIGURE No. 3

SALINITY OF WATER
NEAR BIKENIBEU.

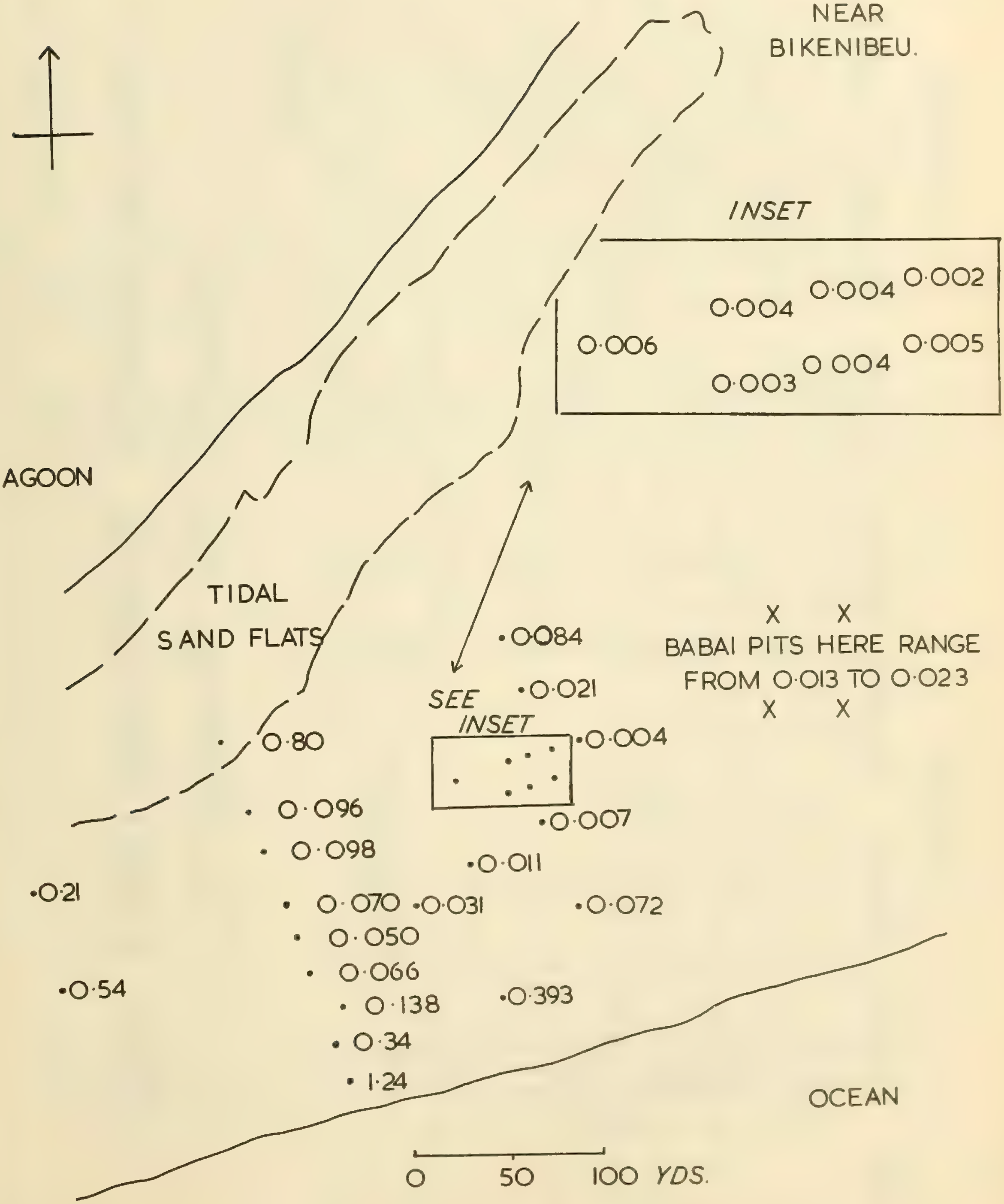
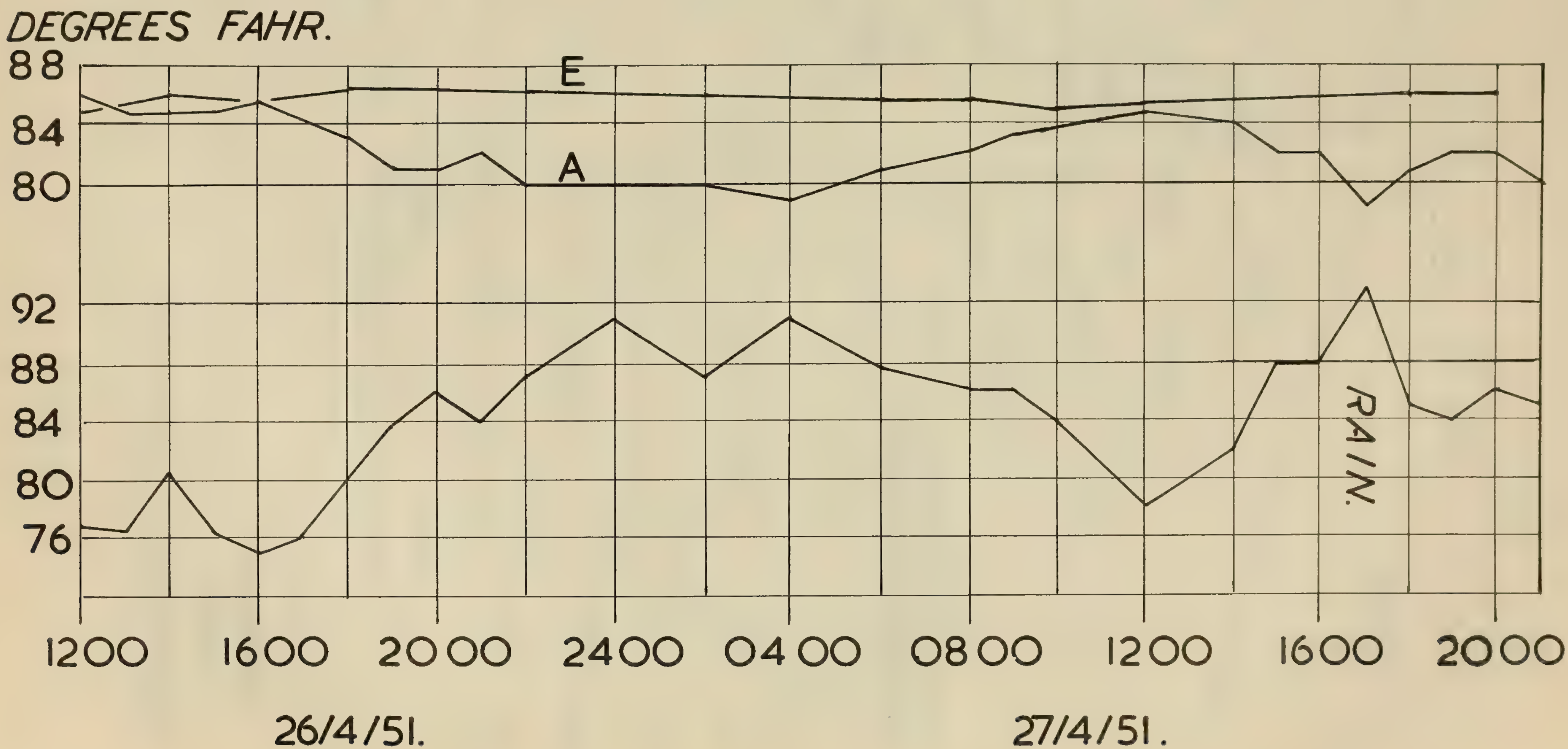


FIGURE No 4

AIR & EARTH TEMPERATURES AND RELATIVE HUMIDITY.



that the central wells reach their maxima and minima one and half to two hours later than the one nearest to the beach, although there are some peculiar irregularities.

There is a very great variation in the salinity of ground water even within a short distance. Figure 3 shows the salinity (expressed as percentage of chloride) in a number of samples near Bikenibeu. The analysis was carried out by silver chloride titration. In little over 100 yards in a transverse direction, salinity fell from 1.24 percent to 0.066 percent Cl. This decrease of salinity from the beaches to the centre of the island is normal. Variations also occur in a longitudinal direction for example, from 0.070 percent to 0.011 percent in two hundred yards. Water from well No. 3, having a salinity of 0.138 percent Cl was unfit for drinking or washing. Well No. 5, at 0.050, was all right for washing, but unpleasant to drink, while water from the best source, 0.002 percent Cl, was indistinguishable from fresh water. Most wells are presumably sited by guess; and a preliminary survey would obviously be of great value when a new one is to be built.

Salinity also varies with time, due to rainfall and evaporation. Wells which are normally sweet became brackish in the drought of 1950. The following table shows the variation of one well at intervals of a few days, with the amount of rain recorded in the intervening periods.

TABLE NO. 2

Variation of salinity in well No. 6 at Bikenibeu

Date		Percentage Chloride	Rainfall between analyses (in inches)
April	26	0.054	
1951	28	0.047	0.965
	30	0.044	0.375
May	1	0.025	0.16
	4	0.029	0.76
	8	0.024	1.72
	9	0.024	0.14
	12	0.028	0.01

The extent of the variation appears to vary from place to place, shown by Table No. 3 which gives the analyses of the nine wells on two different days. The tendency appears to be for the most saline wells to fluctuate most.

TABLE NO. 3

Salinity of the Bikenibeu wells on two dates

(expressed as percentage of chloride)

Well No.	Date of Sampling: 6-April-51	Date of Sampling: 12-May-51	Percentage Reduction:
1	0.93	0.526	43.4
2	0.42	0.288	31.4
3	0.15	0.163	- 8.6
4	0.054	0.040	25.9
5	0.073	0.070	4.1
6	0.070	0.028	60.0
7	0.104	0.068	34.6
8	0.105	0.076	27.6
9	0.585	0.208	64.4

Plants differ very greatly in their tolerance of salinity, mangrove obviously being the most tolerant since it grows in sea water. "Te Ngea" (Pemphis acidula), a saltbush with very hard wood, grows very close to the water, mainly on the lagoon shore, and the two shrubs "Te Mao" (Scaevola sericea) and "Te Ren" (Tournefortia argentea) grow everywhere, even on the beach crest on the ocean side where they are exposed to salt spray. "Te Uri", another shrub or small tree (Guettarda speciosa) is slightly less tolerant, as dead plants can frequently be seen on the beach crest; however, many seemingly-dead trees sprout again from the base of the trunk. "Te Itai" (Calophyllum inophyllum) is a hard wood often growing close to the water on the lagoon shore. Coconuts and Pandanus both grow fairly close to the sea but not as close as any of the foregoing plants. As mentioned earlier, many coconuts growing on small islets or on narrow promontaries were killed in the 1950 drought. At Bikenibeu, healthy coconuts were growing on the ocean side of the first well which on analysis after a fairly dry period showed 1.24 per cent of chloride. Table No. 2 however, shows that this high figure is not constant. The first effect of severe drought is to reduce the size of the young leaves of coconut palms growing under hard conditions; this results in a typical

flat-topped appearance. Trees were seen at Temaiku which had been severely affected and which were just starting to grow normally again.

Introduced flowering trees and others are frequently seen in the villages, which are all on the lagoon side. For example, at Marenanuka, Frangipani and Oleander were growing and flowering on a somewhat restricted scale, setting few seeds. These trees were near a well in which the water contained 0.042 per cent of chloride, a fairly low figure. Breadfruit trees in the same area were healthy, though in most villages individual trees here and there had been killed off by drought.

GARDENING EXPERIMENTS

With the exception of kumala (sweet potato) cultivation, such as at Buota and Betio (in occasional patches) gardening is confined to Europeans, who frequently bring soil into the Colony and grow plants in drums with some success Selected black soil also gives good results especially if enriched with compost; but the effect of added organic matter such as leaves, manure, and fish offal appears to be confined to the first or first two crops only. Excellent tomatoes, China cabbage, English cabbage and water melons were seen on such selected soil (grown by Mr. Carter at Bonriki). Lettuce can also be grown. Frequent watering with good water is of course necessary. Pumpkins will grow in ordinary good soil A climbing bean (Dolichos lablab) at Betio was seen which spread over the roof of a house, yielding well; but another at Bonriki in prepared soil suffered severely from chlorosis and yielded no fruit.

Seeds were taken from Fiji in the hope of establishing a leguminous cover but results were disappointing. In the first nursery, a good site was selected by Dr. Catala to the west of the Bikinibeu house and natural conditions were observed - no watering or manuring was given, but the rainfall after sowing was good.

Sown 24 March 1951:

Leucaena glauca - 'vaivai' - grew rapidly at first, slowing down later - 3 to 4 inches in two months. Slight paleness shown after one month. Likely to persist.

Centrosema pubescens - Never advanced beyond cotyledonary leaves.

Calopogonium mucunoides - First true leaves were yellow and soon died, the cotyledons persisting for some time before dying.

Sown 27 March 1951:

Cajanus indicus - Pigeon Pea - Died after producing two or three leaves. One only still persisted after two months.

Desmanthus virgatus - Appeared yellow and grew extremely slowly.

Pueraria phaseoloides - Hawaiian Puero - 4 or 5 seedlings only. Given soil from near Puero roots at Sigatoka Agricultural Station, Fiji. One grew very well until checked by the attack of a leaf-cutting bee; the others small but of a fairly good colour. Hopeful .

Stylosanthes guianensis - Growth stopped after 1 to 2 inches. Yellow.

Panicum maximum - Guinea grass from Sigatoka Agricultural Station. A few plants germinated after a month and had reached 2 inches by June.

P. maximum var. coloratum - Purple Guinea. Grew rather better than the common guinea grass, but neither is expected to survive.

Sorghum verticelliflorum - Kavirondo Sorghum. Whitish yellow - stopped growth at 6 inches.

Canavalia ensiformis - Sword bean. Rapid growth after germination followed by dying-off of the growing point in every plant except one.

Rice Bean - yellow leaves, but still growing after 5 weeks. (Very thickly planted). Growth appeared to be stopping at 2 inches.

Pawpaws and water melon were also sown for the sake of comparison; the pawpaws made slow growth but the melon seedlings died off.

Later sowings by Dr. Catala on 24 April 1951 were also disappointing.

A second nursery was made to the east of the house at Bikinibeu and different treatments applied. Calopo, Vaivai, Pigeon Pea and Kavirodono Sorghum were sown in 4 parallel beds which were divided into 8 sections by divisions at right angles to the lengths of the beds. Soil from corresponding legume roots in Fiji was applied to half of the plots of each of the three legumes.

Each group of 4 plots was then given 4 treatments as follows:

(1) an NPK mixture: sulphate of ammonia, muriate of potash and super phosphate;

(2) a solution of trace elements, including iron, manganese, magnesium, copper, zinc, molybdenum and boron;

(3) Coconut meal. Application of this was delayed until early May as a result of its being misplaced on the ship.

(4) Control.

The seeds were sown thinly and the seedlings were watered twice in their early stages.

The legume soil benefitted the Pigeon Pea but not the other legumes. Where it was applied, the Pigeon Pea had reached 2 feet and was still growing at the end of May, although attacked by the leaf eating bee. The untreated plants had mainly died out.

The NPK manures gave no effect.

The trace elements gave a slight response on the Kavirondo Sorghum - slightly better growth with a better colour.

The coconut meal had insufficient time to give results by the end of May

The calopo in this nursery reached the 2nd and 3rd leaf stages, but these leaves were very pale. The Leucaena grew as in the first nursery. The Pigeon Pea looked as if it might reach maturity where it had received a sprinkling of soil. The Kavirondo Sorghum was a better colour than in the first nursery but was decidedly yellow. However, it appeared to be still growing at 8 to 10 inches.

The results obtained from the nurseries are mainly negative but are nevertheless very interesting. It remains to be seen whether the Leucaena will become established. Greater response to the trace elements had been anticipated. The delayed application of coconut meal was unfortunate because it seems likely that it may have considerable effect over a period of time.

LIVESTOCK

Pigs are kept by the majority of householders in the villages. Most of the pens, which are usually just behind the village, are simply four pieces of Airstrip matting forming a square. Higher walls of two sections are not usual. The alternative to these iron strips is a wall of interlaced coconut trunks. Pens are usually in the shade; shelter is usually provided (by plaited coconut leaf) if they are in the open.

The pigs are of varied breeding; the only definite statement that can be made is that no Tamworth influence was seen. All are small. This is not entirely due to nutritional deficiencies as a boar imported from Fiji and his offspring are noticeably bigger than average. The most frequent type is a porker weighing up to 200 lbs. at a year or so; but unfortunately no details could be gathered as no pigs of known age were found. The people simply do not know. Interest in breeding is very low; boars were seen which were no more than 50 lbs. in weight - little runts not much bigger than a decent-sized weaner. On the other hand, a son of the Fiji-bred boar mentioned above (which was imported by the Catholic Mission at Teaoraereke 4 years ago), was seen at Buariki. This pig was about 2 years old, well grown and much above the average for Tarawa. It was recently castrated because it got out of its pen and caused trouble; so it is now being fattened up. It was less trouble to castrate it than than to make a strong pen. When the people in this village were asked if, supposing a good boar was available, they would pay one shilling service fee, they suggested giving half the litter at birth to the owner of the boar instead.

Litter sizes appear to be very small and the average number reared is probably only about three. Nutrition is almost certainly the limiting factor. Feeding does not vary greatly; indeed, it cannot, so limited are the foods. They comprise coconuts, herbs, and fish bones. Two to five coconuts are fed either once or twice a day. The common method is to feed once a day, giving water in the evening. The two small herbs 'Te Mtea' and 'Te Wao' (Portulaca lutea and Sesuvium portulacastrum) are commonly gathered by the children. Both are plentiful. Grass and babai leaves may

also be given, and possibly 'Te Bero' (Ficus sp.). Some people give toddy - presumably what is left over from their personal requirements.

Emaciated pigs were seen which were neglected by their owners and not fed regularly. Also one gilt was seen which had the same food as another, neighbouring, fat sow, but apparently this one could not digest coconut, and so was very thin. The gilt was little more than 50 lbs. and had one pig of about 25 lbs. The fat sow had had three litters; six in the first all died in a week, nine in the second all died in five days, and one was reared out of seven in the third litter.

In Eita village there were 12 gilts and sows, 2 boars, 10 weaners and porkers, and about 6 young pigs running loose. In Bikinibeu there were 18 gilts and sows, 2 boars, 9 weaners and porkers, and about 14 young pigs. (Both villages have populations of 124).

Paralysis of the hind quarters was seen in one sow, which had full use of its forelegs. One sow was seen with a swelling of the udder. Slow growth of some pigs was presumed to be due to worms. Lice were reported but not seen.

The listlessness of the people regarding pig husbandry and the unavailability of feeding stuffs to give a balanced ration combine to make significant improvement in pork production unlikely.

POULTRY

The majority of birds run loose in the villages, but sometimes fowl runs are seen, made of 'Te Ba' (coconut mid-ribs, which are 8 to 10 feet long). There is a great variation in breed and size, ranging from well-bred Rhode Island Reds kept by various European houses on Bairiki (such as the Residency), down to bush fowls weighing only a pound or two. Occasionally good looking birds are seen in the villages, and some birds live wild in the bush.

Their food is mainly coconuts, with what else they can forage. At the mission at Teaoraereke, a big increase in egg production following the feeding of fish was mentioned. This indicates that considerable increases in poultry production should not be difficult to achieve.

Ducks are not very common, but some Muscovies were seen, one with a very good brood of ducklings.

No geese were seen.

TOOLS

Tools used in agriculture are very few and very simple. For cutting the many coconut roots which are in the soil everywhere, a spade with a circular blade is preferred. The blade is flat, and about 6 inches in diameter. The handle is commonly 5 feet of 3/4 inch pipe, which gives momentum to a cutting stroke. This spade, 'Te Rereba', is mainly used for digging or extending 'babai' pits.

Just as a Fijian is not often without his cane knife, so a Gilbertese usually has a machete type of knife, which is used for opening drinking nuts, cutting copra, and so on.

A mallet, 'Te Ikuiku'is made out of 'Te Ngea', a hard wood shrub (Pemphis acidula). Such mallets are used for beating flat the mid-ribs of pandanus leaves.

Other domestic tools are coconut scrapers (similar to those in Fiji) and scrapers for pandanus fruit. There are of course various articles for fishing, ranging from canoes down to fishhooks.

IMPROVEMENTS POSSIBLE IN THE NATIVE AGRICULTURE AND PROBLEMS REQUIRING FURTHER INVESTIGATION

The subjects requiring investigation are divisible into the problem of increasing exports, which means increasing copra production ; and the problem of increasing food production in order to provide for the increasing population, to lessen the dependence on overseas supplies, and to give a more varied diet..

An immediate improvement is possible in the quality of copra by reducing the interval between cutting and drying, and by taking more care during drying. At present, the coconut owners spend a day cutting copra and bring the wet copra back to the village for drying next day - an interval of up to 24 hours. To produce white copra, this interval should be reduced to less than 4 hours. To prevent contamination with sand and dirt, and to speed the drying process, drying trays should be erected above ground level, and should be provided with movable covers of galvanised iron or other rain-proof material.

The use of hot-air driers, for the production of good quality copra even in rainy weather, should be investigated. However, care is needed to prevent a trade developing in green copra between growers and Co-operative Societies, as this would inevitably cause delayed drying and consequent reduction in quality.

To encourage the production of better quality copra it will be necessary to introduce a grading system* coupled with reasonable price differentials between grades. Particular attention should be paid to thorough drying of copra. Encouragement of half-nut copra (obtained by husking prior to splitting, instead of by extraction using a knife) would result in less fragmentation and less dust, and probably higher oil content; but a longer drying period is needed. Finally, quality should not be lost during storage by allowing insect infestations to develop; a routine spraying of the sheds is recommended.

Management of the coconut groves could with certainty be improved by weeding the bushes and germinating nuts, by removal of aged and non-producing palms, and by a prohibition on burning within the groves.

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* Copra grading was instituted in 1957.

It is highly probable that increased yields would also result from selective thinning in most places, and by the establishment of a leguminous ground cover; but these should be investigated before being advocated on a wide scale. The cover crops Calopo and Centro were unsuccessful at Bikenibeu but the beach pea *Vigna marina*, which flourishes on Funafuti is more likely to be suitable. There is insufficient evidence on which to base a firm recommendation for optimum spacing, but it appears that ten yards is too wide and gives insufficient ground shade. Eight yards triangular planting is tentatively suggested.

Very considerable losses occur in certain places through delayed collection and incomplete collection of nuts, resulting in partial or total losses through germination of the nuts. This problem is economic rather than agricultural, and is related to the problem of better utilisation of land held by absentee owners. A possibility worth investigation is the alteration of the export tax on copra into a land tax. This is considered possible since an overwhelming proportion of the land is used for coconut production. It would be necessary either for the tax rate to vary with the year's productivity, which depends on the rainfall or that there should be a flat rate with a reduction in drought years. It might also be necessary to reduce the rate in infertile areas.

The most important long-term measure in improving the crop lies in better planting of better nuts on unplanted land. No areas were seen on Tarawa which require felling and replanting, and it is not known if this would be justified on other islands. Selection of seed nuts of good shape from high yielding trees followed by rigorous selection of seedlings would not be difficult to carry out, but does not appear to have been thought of.

Recent figures for copra produced by the Gilbertese may be mentioned here. They are from the Colony copra Board's Annual Report for the year ending 31st March, 1958:

1951	1952	1953	1954	1955	1956 (drought)
4,019	3,956	7,705	5,770	7,180	2,900 tons.

It is certain that more 'babai' could be grown, mainly by greater attention to the existing area. Yields under different methods of management require study. For example, the pig manure is all wasted. The legume *Gliricidia* grows on Betio and Bairiki and could possibly be grown round the banks of pits, and used for mulching together with the pig manure. Varietal differences such as salt toleration, rate of growth, and yield are unknown. A comparison of the yields of *Colocasia* and the two main *Cyrtosperma* varieties 'Te Katutu' and 'Te Ikaraoi' over different intervals of time would be very interesting. Finally, a method is required to encourage the sale of 'babai' through the Co-operative Society to the people on Bairiki and Betio.

A point scarcely agricultural yet not out of place here concerns the use which might be made of mangrove; considerable protection could be given to the road where it crosses between islets by judicious planting of seedlings. The first stage of land reclamation on the lagoon shore could be construction of fish ponds, their banks being protected by mangrove.

Little improvement in pig keeping is possible without a big increase in interest among the owners. Selective breeding following the use of good imported boars could give big results if combined with better feeding standards. It is certain that a considerable amount of fish is necessary in the ration. Because of the difficulties of feeding, it is unlikely that pig keeping will ever get out of the "backyard" stage.

The poultry are probably well adapted to a frugal life and again, breeding for better size and egg laying could not be successful unless accompanied by better feeding, which however presents no great difficulty on a small scale.

No geese were seen; it is suggested that they should be tried, for they could make good use of the grass where it grows well, and provide animal protein to the human diet. Provision of grazing for them would also benefit the coconuts.

Many of the problems mentioned above could be studied on a small station, provided that appropriate personnel were available. The area around the house built at Bikenibeu is considered to be sufficiently typical. A plant introduction garden could be located near the fresh-water well. About 15 acres would suffice in the first instance.

In conclusion, I wish to acknowledge with gratitude the help given by His Honour the Resident Commissioner, the Director of Education, and many other officers of Government, and by Chief Kaubure Taniera and Assistant Master Toki.

ATOLL RESEARCH BULLETIN

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Birds of the Gilbert and Ellice Islands Colony

by

Peter Child

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CONTENTS

Birds of the Gilbert and Ellice Islands Colony

by

Peter Child, B.Sc., Dip. Ed. (N.Z.)

INTRODUCTION

The following notes and observations by an amateur bird-watcher are the result of additions and amendments to a booklet which I wrote while Education Officer at Tarawa, Gilbert Islands, and originally published in January, 1956, as a guide for native schoolteachers of the Colony.

I had lived from August 1943 to December 1944 in the Ellice Islands as a radio operator in the Coastwatching Organisation during the Second World War. No systematic notes on the birds were made during this period although many details were later recollected, especially when these islands were again revisited during the second tour of duty for the three years February 1953 to February 1956. This recent post was a travelling one and I was fortunate in being able to visit nearly all the islands in the Colony with the exception of the Northern Line Islands and the uninhabited islands of the Phoenix group. (For information concerning these exceptions acknowledgement is made to the authors of relevant publications quoted in the bibliography accompanying this paper, and to acquaintances who had visited these places and supplied me with verbal reports.) The nature of my work generally necessitated living on each island for periods of several days and thus allowed opportunity for studying the bird-life and visiting (usually by canoe) many remote islets and breeding places which were not inhabited by the native people and which the casual visitor never reaches. These are, of course, the real undisturbed bird sanctuaries of the Colony, where the avifauna is at its best and least afraid of man.

It should be mentioned that no comprehensive survey of the whole Colony has been carried out by a competent ornithologist, and thus there is a noticeable gap in the available literature of the Pacific birds. For the same reason the subspecific names of birds in the western parts of the Colony (i.e. the Gilbert and Ellice groups and Ocean Island) are somewhat in doubt, but the most likely one I have obtained is given in the following notes.

The scientific nomenclature follows that given in Peters' "Checklist of the Birds of the World."

Geography: The Colony comprises 37 coral atolls and islands spanning the central Pacific Ocean. While the land area is very small, approximately 369 square miles, the distances between islands and groups of islands are vast. From Ocean Island in the west at longitude 169° 35' E. it is some 2200 miles to Christmas Island at longitude 157° 28' W. in the east; and from Washington in the north at latitude 4° 7' N. it is some 1000 miles to Niulakita at latitude 10° 45' S. in the south. Such a rectangle of

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* 41 Brandon St., Alexandra, Central Otago, New Zealand.

sea, though not exclusive to the Colony, covers an area of more than two million square miles.

These islands form four groups: there are 16 Gilbert Islands, 9 Ellice Islands, 8 Phoenix Islands and 3 Line Islands; with Ocean Island as an outlier from the Gilbert Islands. The 8 Phoenix Islands include the British-American Condominium of Canton and Enderbury (1939); also, three of the British islands of the Phoenix group, Birnie, McKean, and Phoenix, are uninhabited. The Gilbert and Ellice Islands form a chain lying in a N.W. - S.E. direction astride the equator between longitudes 172° E. and 180° E. The Phoenix Islands are scattered south of the equator between longitudes 171° W. and 175° W. and the three Line Islands, Washington, Fanning and Christmas, lie in a N.W. - S.E. line north of the equator between 157° W. and 160° W.

Geologically Ocean Island stands apart, being an island of the elevated type, its highest point being 280 feet above sea-level. This island is approximately 1500 acres in extent and contains rich deposits of almost pure phosphate of lime on top of the coral base. All the other islands belong to the Central Pacific "area of subsidence," having been formed by the upgrowth of coral around the flanks of mountains long since submerged. Most are atolls, with a ring of reefs and islets enclosing lagoons, the land surface rarely rising more than 15 feet above sea level. A few of the islands are not typical atolls but consist of solid masses of limestone surrounded by fringing reef, one or two having small land-locked lagoons. One (Washington), has a land-locked lagoon which has become a freshwater lake with peat bogs surrounding it.

Bird-life in general: To one who has spent nearly all his life in inland New Zealand, the experience of living so close to the sea (in fact, with the sea) on tropical atolls and observing the very different kinds of birds from those one has been accustomed to, has been a source of great enjoyment and surprise. Prominent among the novelties were

(1) the absence of "singing" birds;
(2) the uncommoness of true land birds, by far the majority being oceanic birds and migratory shore birds;
(3) the large number of migratory species which make these atolls their winter quarters, or a 'halfway house' on their long flights north and south;
(4) the noisiness of some species during the night;
(5) the absence of any very small birds (except the Christmas Island "canary" which I have not seen).

Perhaps the food-gathering of sea-birds, demanding as it does much time and prolonged journeys on the wing, is the factor which determines their sizes and wing-spans. In any case, it makes observations and identifications easier for the bird-watcher, and the uncomplicated backgrounds of sea and sand make the task beautifully simple in comparison with the inland and forest habitats of New Zealand.

It seems almost certain that there has been a general decrease in the resident bird population of the Colony over the past two or theee human generations, particularly among the more timid and ground-nesting species. Old men who can remember back before the turn of the century have often told me of birds which used to nest on their islands but which

are now rarely, if ever, seen. There also exist some Gilbertese bird-names which the present generation are unable to associate with any particular species now known to them. There appear to be four reasons for this trend: (1), a rapidly increasing human population since the cessation of activities of the "black-birders" about 1880, with subsequent expansion to previously uninhabited islets, increase in killing for food, and general disturbance of colonies; (the black-birders were slave traders who took natives to work in plantations in Mexico and guano mines in Peru.); (2), considerable shooting for food and feathers by the early traders, which may have wiped out small breeding colonies; (3), the increasing numbers of dogs, cats, and rats (the last-names especially since the Second World War), with consequent destruction of eggs and young; and (4), the disturbance caused by military occupation and the construction of airstrips on some islands during 1942-46. Ground-nesting species also suffer from the predations of crabs, especially hermit crabs.

The Gilbertese as a race have apparently never been great bird-eaters, whilst the Ellice people have (and still are). In spite of legal protection, it is not an uncommon sight to see a party of Ellice youth who have been working in the bush return with a "bag" of plucked noddies for roasting over a coconut-husk fire. (In the Gilberts it is mainly in the southern 'drought'islands where any birds are eaten.) Other birds occasionally eaten are frigates and boobies (caught while asleep on coconut palms), pigeons (trapped in special snares or taken as nestlings), and curlews and herons (which are sometimes shot). The eggs of the Grey-backed Tern which breeds in thousands in the Phoenix group, and the Sooty Tern on Christmas Island, are eaten in times of food shortage.

Seabirds have always been reliable guides to interisland voyagers and fishermen, particularly in this Colony where the low-lying atolls are invisible from a few miles out, and where fish form a large proportion of the native diet. The activities of noddies, terns, and others often betray the presence of good shoals of bonito, trevally, and other useful food fish; their regular excursions from islets to fishing-grounds, especially in the early morning and evening, provide a valuable guide for canoe-captains as to the whereabouts of land. Probably much of the old Gilbertese navigation was based upon the regular flying-routes of seabirds. In the Ellice the "tautai' (fishing-captains) have many omens and beliefs associated with the calls, movements and other mannerisms of sea and shore birds.

The scattered islands of the Colony are situated on or near the equator and, although there are occasional stormy westerly periods from November to February, the daily weather and temperatures remain remarkably constant, with prevailing winds from easterly quarters, throughout the year. Because of this great uniformity of seasons the nesting periods of birds are often prolonged affairs, and there is nothing like the same urgency and definiteness one is accustomed to in temperate lands. The Brown Noddy, for example, has been observed nesting at every month of the year! It has also been established that the Sooty Tern, and possibly the Grey-backed Tern, have breeding intervals of less than twelve months.

The commonest and most widely distributed species is probably the Black Noddy, while one of the rarest is the Brown-winged Tern. It is most likely that other species, especially migratory waders, will be reported

from the Colony from time to time. The names are shown as follows:

Scientific Name (Peter's Checklist) English Name
Ellice Name Gilbertese Name

Some alternatives are given in brackets.

PART A: RESIDENT BIRDS

I. STERNIDAE (TERNS AND NODDIES)

TERNS or "sea swallows" are the most conspicuous group of birds of this region. The tern family consists of birds of smallish body size having long narrow and pointed wings and long forked tails. The legs are very short and feet small and webbed. The bills are straight, tapered and quite long. When in flight over lagoons or the ocean searching for food the bill is characteristically pointed downwards more or less at right angles to the line of the body. They dive with folded wings from a considerable height into the water and quickly emerge again with their prey, which consists of small live fish, crustaceans, cuttlefish and other small creatures from near the surface of the sea. They prefer live food, and are not scavengers like gulls.

Terns are sociable birds, living and breeding together in huge colonies or "terneries", the noise of which is sometimes deafening, even throughout the night. Males and females are alike in all species. All except the White Tern lay their eggs in hollows on sandy or shingly beaches. Most tropical terns lay only one egg but the black-naped Tern, and very occasionally the Grey-backed Tern, often lays two. Even among terns of one species eggs vary considerably in size, shape and colouring, and hardly any two specimens are exactly alike. The eggs and chicks are usually protectively coloured and difficult to spot among the stones and sand.

1. Sterna sumatrana sumatrana. Black-naped Tern.

Akiaki. Kiakia.

This small tern is easily distinguished by the black band around the head above the eyes and extending down the nape. Except for the mantle and upper wings, which are a very pale grey, most of the bird is white. The primary wing feathers often have dark grey or blackish tips; the bill and feet are black, and the webs also black. The crown is white. Young birds in immature plumage have somewhat darker mottled colouring.

This bird is common to most western lagoon islands, especially where there are small uninhabited islets of sandbanks such as bikeman (Tarawa), Abanekeneke (Onotoa), Pukasavilivili (Funafuti), and Teafüave (Nukufetau), which are the favourite breeding places. It does not appear to be present in the Line Islands and is relatively uncommon in the Phoenix.

Nesting extends from January to September. The nest is just a shallow depression in the sand or among small coral shingle or among high tide

debris, sometimes sheltered by a tuft of grass or a low saltbush or other shrub. Two eggs are frequently laid. They are smaller than the White Tern's and are pale greenish-blue in background colour with pale mauve spots and blotches all over, and dark brown blotches and markings superimposed. On shingly beaches the eggs are very difficult to see. The average size of 11 eggs measured was 37 x 26 mm.

Sterna fuscata oahuensis.	Sooty Tern. (Wideawake Tern)
Talaliki.	Keeu. (Kereekere)

The Sooty Tern is a rare bird in the Gilbert and Ellice groups, there being small colonies only at Teafualiku (Funafuti), Numatong (Nonouti), and Oneke (Kuria). They are very common in the Phoenix and Line Islands, where they sometimes nest among their cousins the Grey-backed Terns. The adult bird has a broad white band on the forehead extending above the eyes; the crown, nape and upperparts are dull sooty black, while the underparts are white, with some greyish feathers under the tail, the bill and feet are black.

According to observations made by Dr. J.P. Chapin, an American ornithologist, and verbal reports to me by the British District Officers who have been stationed on Christmas Island, the Sooty Tern has a breeding interval of only six months there, nesting taking place regularly every June and December.

King quotes a Gilbertese living there as stating the nesting seasons to be December-March and June-August. I have not been able to determine whether a similar cycle occurs in the Gilbert and Ellice colonies; nesting was in full swing with fresh eggs at Nonouti in May, the colony being about 120 birds. One older egg, two flying young and three adults were seen at Funafuti in September, and according to locals the nesting was nearing its end there at that time, the normal population being in "hundreds"; between nesting periods the birds migrate elsewhere - the locals say to the Phoenix group.

A large single egg is laid in a shallow hollow in the sand; it is pale bluish or buff in ground colour, with purplish brown spots and blotches. The eggs vary considerably in size, shape and colourings. The average of 13 eggs measured at the Nonouti colony was 49 x 34 mm. Fishermen, ships' crews and islanders often collect the eggs for food where they are common.

The high-pitched screech of the Sooty Tern is imitated in the common Gilbertese name of "keeu".

3. Sterna anaethetus anaethetus. Brown-winged Tern.

? ?

I have not found anyone in the Colony able to name this bird from a description. Blackman states that it breeds in the 'Phoenix and Ellice Islands'. They were recorded at McKean Island, Phoenix group, by Graffe in 1863 (Finsch and Hartlaub 1867). Sharpe and Whitmee (1878) listed it without giving any details in a collection from the Ellice Islands. Buddle observed several pairs among a large colony of Grey-backed Terns at Canton in June, 1937, but no sign of nesting was discovered.

3 birds seen by the writer at Teafualiku islet, Funafuti (Ellice Is.), seemed to be of this species; they were flying but appeared to be an adult pair and an immature. The natives said these birds nest there but could not be distinguished from the more common Sooty Tern, and there was no separate vernacular name for them. (The adult is similar to the Sooty Tern but is smaller and slightly lighter in colour, and has a narrower white band on the head which extends back beyond the eye. The bill is black, the legs and feet dark grey or black with brownish webs.) The nesting habits were said to be similar to those of the Sooty Tern. During the same month (September, 1955) a young bird brought from Funafuti was examined at Nukufetau, and answered the description given by Alexander for the Brown-winged Tern, and its measurements indicated a smaller bird than the Sooty Tern. (Bill: 1.4; tarsus: 0.9; length: 14.0; wingspan: 28 inches.) However as the colouring of the two species is almost identical, and as it was only the immature which was handled, the identification remains in some doubt. It seems possible that a small colony of this species mingles with the Sooty Terns during the breeding season at Funafuti.

4. Sterna lunata. Grey-backed Tern.
(Bridled Tern; Spectacled Tern)

Talaalofi. Tarangongo.
(Maningongo)

These birds are no longer breeding in the Gilbert and Ellice groups, although it seems that they did so on a few islands in days gone by. They still breed in immense colonies in the Phoenix Islands. There is a very large colony on the southeastern end of Canton.

The adult is similar in build to the Sooty Tern but slightly smaller, and the upperparts are soft grey instead of sooty black; the underparts are white and the feet and bill black. The head is black except for a white forehead and a white band extending back above each eye.

The birds nest on the ground, laying their eggs in hollows among stones and creepers; sometimes the hollow is lined with small bits of coral and rock (Bailey once recorded two nests with two eggs in each, at Canton.) Undoubtedly May-June is the height of the nesting season as recorded by observers on Canton, but, according to one boy informant of mine, a native from Hull Island, the species has two nesting seasons per year, the second being in December.

The eggs of this species are sometimes eaten at Manra (Sydney) and Orona (Hull), especially during times of drought when food is scarce.

5. Thalasseus bergii.	Crested Tern. (Swift Tern)
Tala (Talaalofi)	Karakara. (Kabiniwa)

The eastern subspecies is T. b. cristatus while that in the west is more likely to be T. b. pelecanoides, according to Baker.

With a wingspan of about 40 inches, this is easily the largest tern in the Colony. It is unknown at Nui, Niutao and Vaitupu, but otherwise appears to be present in small numbers on most islands.

The crown and nape are black with elongated feathers from the nape forming a crest from which the bird is named. The upperparts are light and dark greys while the neck and underparts are white. The feet are blackish with dark webs. A conspicuous feature which helps identify this bird is the large yellow bill. It dives for fish from a considerable height, and is often seen hovering over the lagoon shallows uttering the harsh cries from which the Gilbertese name 'karakara' is obtained. The other name, 'kabiniwa' means 'canoe-hull' and probably refers to the shapely body of this fine bird.

Crested Terns are said to nest in small colonies on sand or gravel bars similar to those occupied by the Black-naped Terns. However, no one was ever able to show me an actual nest or egg, and in none of the literature is there a report of finding them. It is said that one egg is laid between December and February. I saw several immatures in July at Onotoa, and Moul records one from there on August 19. In May an immature bird was being fed small fish by a parent on the lagoon reef at Betio, Tarawa.

NODDIES belong to the same family as terns, and in appearance and habits they are similar to terns; the two most widely distributed noddies found in the Colony are, however, much darker in colour than any of the terns and so are easily distinguished from them. The fork of the tail is not so deep on noddies as on terns, and in flight noddies often have the tail closed so that the fork is not noticeable at all.

Their food is similar to that of terns but, unlike terns, they do not dive below water for it from a height but skim around fairly close to the surface and plunge in briefly when the prey is sighted. Although their feet are webbed noddies spend very little time on the surface of the water as their feathers soon become waterlogged; occasionally flocks of birds are seen during fishing operations resting on the ocean or lagoon.

6. Anous stolidus pileatus. — Brown Noddy. (Common Noddy)

Ngongo. (Uii) — Io.

This is the largest of the noddies and is readily identified by its dark brown colour. The crown and nape are pale grey, almost white on the forehead, and there is a black band from the bill to the eye. There is a prominent white semicircle under each eye. The rest of the body is dark brown with lighter brown shades on the underparts. The bill is black and the feet brownish-black with yellowish webs.

They are fairly common on all islands of the Colony. In some places, such as Canton and Christmas Island, they have been known to nest on the ground among coral blocks, but the favourite nesting place is the butt of a coconut frond, in the axil between the butt and the main trunk; this site distinguishes them from the Black Noddy which nests further out on the petiole where the small leaflets begin. At Onotoa two nests were found in the whorls of leaves of the pandanus.

A rough nest is made of twigs, dead leaves, roots, and coconut fibre. One large egg is laid, pale buff in ground colour with large purplish-brown spots and blotches, more dense towards the wider end. Average size of eggs measured at Nonouti was 52 x 34 mm. Nesting seems to be most common between March and September, but eggs may be found in different localities during any month of the year.

The adults utter a very harsh cry, "krrrrr", from the tree-tops, especially when their nests are disturbed. They are sometimes nicknamed 'the angry birds' by the natives because of this habit.

7. Anous minutus minutus. — Black Noddy. (White-capped Noddy)

Taketake. (Lakia) — Mangkiri. (Kunei; Takiri)

This is a smaller dark-coloured noddy, and probably the commonest bird in the Colony, being listed in large numbers on all islands visited by the writer. Its general colour is very black with a noticeable contrasting white crown and forehead and a white semicircle under the eye. The bill is black and the feet dark brown, almost black.

The birds congregate in large colonies, especially during nesting time, and their continual chatter can be heard from afar. As mentioned above, one of their favourite nesting places is on palm fronds where the small leaflets begin to grow out from the rib, and on some trees one may find a nest on almost every near-horizontal frond. On some islands Tournefortia and Pisonia are the favourite nesting trees, while on others with dense colonies where trees are limited nests may be found on the ground. Several nests may occur on one branch, and even on coconut palms two and three on one frond are not uncommon. The nests are roughly

constucted of small twigs and roots, dead leaves, old feathers and other scraps of rubbish, stuck together with droppings, the whole forming an untidy and smelly mess. In dense colonies the ammoniacal smell of excreta is almost overpowering, there being a thick coating of decaying leaves and droppings over the ground and lower branches. Only one egg is laid, creamish or buff or bluish-olive in ground colour, with purplish-brown blotches and spots, more dense near the wider end. The eggs vary in size, shape and colourings but are always smaller than those of the Brown Noddy. Average of 15 eggs measured was 43 x 30 mm.

The season lasts mainly from February to October, with the greatest activity perhaps in June, but some eggs may be found in different places all the year round. There are very large breeding colonies of thousands of birds on Numatong (Nonouti), Tabuarorae (Onotoa), Namauri (Tabiteuea) and Nikumaroro (Gardner Island). Smaller colonies are scattered throughout all the other islands. I once spent a night among the Numatong colony; the smell and commotion prevailed throughout and this, together with the perambulations of ghost crabs, dispelled all ideas of a night's rest. Noddies seem to be ever restless, except during the heat of the day which seems to be their quietest period, when they sit among the treetops calling and preening; probably, however, most of the birds are out at sea fishing at this time and, on returning in the evening, the hubbub resumes. Probably because their feathers are less waterproof than those of most seabirds noddies shake themselves in the air after diving or periodically during heavy rain. During extremely heavy rain I have seen them descend and rest on the water.

8. <u>Procelsterna cerulea nebouxi</u> Blue-grey Noddy.
(Bennett's Noddy; Blue-grey Fairy Ternlet.)

Talaliki. ?

This is the smallest of the tern family in the Colony, being only 10 to 11 inches in length. It is entirely light bluish-grey except for paler silvery-grey or whitish underwings; the bill is black and the feet black with yellowish webs.

Now a rare bird in the Gilbert and Ellice groups, a specimen was collected by Whitmee from the Ellice Islands in 1876, probably from Funafuti. They have been observed on several islands of the Phoenix group: McKean (Gräffe in 1863, listed in Finsch and Hartlaub, 1867); Phoenix, Sydney, Birnie, Canton (Lister in 1889). They are common at Fanning (Kirby in 1924), and Christmas Island (King in 1953). The subspecies at Christmas Island is listed as <u>P.c.cerulea</u> by King and also by Alexander.

The nesting period appears to be about July to January. One egg is laid in a hollow among coral or on bare sand, the nest being lined with a few sticks or coral fragments. The egg is pale cream with rich brown spots and underlying pale greyish-brown spots.

9. Gygis alba. | White Tern. (Love Tern; Fairy Tern; Angel Tern)

Matapula. | Matawa. (Matawanaba; Bairuti)

Baker (p. 179) states that the systematic position is in doubt. In the eastern region it is probably G.a.candida as listed by Bailey and others, and by my measurements from live birds caught at Tarawa the subspecies in the west is probably G.a.pacifica, which is a slightly larger bird.

The beautiful little White Tern is fairly common on all islands except Arorae, where surprisingly it is not present at all; pairs of birds will usually be seen hovering near pandanus trees or playing on the branches. They are easily distinguished by their pure white colour and arboreal habits. The shafts of the primaries are dusky brown and of the tail feathers almost black. Mayr describes the bill and feet as black; however all specimens examined by me in this Colony have a bill which is deep navy blue at the tip to a paler blue or royal blue at the base, while the legs and feet are light blue or greyish-blue with white, yellowish or flesh-coloured webs. The prominent dark eyes have a narrow black ring around them.

These birds are not easily frightened and show much curiosity by fluttering close over one's head and uttering shrill nervous calls, especially when one approaches a nesting-site. No nest is built and only one egg is laid; favourite places are the tops of old coconut stumps, forks of pandanus and tree-heliotrope, or simply the rough bark of a horizontal branch of these trees, and sometimes nothing more secure than the top (slightly concave) surface of bare palm frond petioles; needless to say these are precarious places for eggs, yet few are ever seen dislodged. At Ocean Island eggs may be found in hollows and ledges on the large coral blocks and pinnacles which remain after phosphate mining, or occur naturally around the coast.

The eggs are pale bluish-green marked with brownish and purplish blotches and scrawly lines; average size for five eggs measured was 38 x 30 mm. I have seen eggs every month of the year, but the main nesting season is probably about May to January. The young cling to the branch with their small sharp claws and are not easily dislodged. An adult may often be observed arriving at the youngster with a bill full of tiny silvery fish from the lagoon or ocean; it is remarkable how it manages to catch the last few with its bill already half full, for up to a dozen have been seen in a bill at one time. These are fed to the fledgling one at a time directly from the bill. The rather dusty grey down of the chick compares unfavourably with the brilliant snowy whiteness of the parents, but is of considerable value as camouflage on the branch. During feeding operations over the lagoon young flying immatures are often harassed by the noddies who give chase until the tern drops a fish, which is then smartly retrieved by the noddy before it reaches the water.

(Terns and Noddies
(A simple identification chart)

Plumage:	Size		
	Large	Medium	Small
Mainly dark, light crowns.	_____	Brown Noddy	Black Noddy
Dark upperparts, white underparts.	_____	Sooty Tern	Brown-winged Tern
Greyish upperparts, white underparts.	Crested Tern	Grey-backed T.	Black-naped Tern
Nearly all pale grey	_____	_____	Blue-grey Noddy
All white	_____	_____	White Tern

II. SULIDAE (GANNETS OR BOOBIES)

Three members of this family occur in the Colony although only one of them, the Brown Booby, is commonly known in the Gilbert and Ellice Groups, the other two being but occasional visitors.

The birds are similar to the species in New Zealand, large and heavily built, with stout thick necks and very stout powerful beaks, short legs with large webs between all four toes. There is an area of naked skin on the face and throat, the colour of which helps identify the species. The flight is steady and deliberate, usually fairly close to the surface of the water.

The name booby (from the Spanish "bobo" = a fool) appears to have arisen from their apparent stupidity in allowing people to approach them so easily, and because they permit themselves to be continually robbed of food by the frigate-birds. A frigate will sometimes grab the booby by the tail in flight to make it disgorge some fish which the frigate then usually manages to retrieve before it hits the water.

10. <u>Sula leucogaster plotus.</u>	Brown Booby. (Common Booby)
Kanapu. (Kanopatua)	Kibui. (Tairo ?)

Single birds or small groups are often seen flying around lagoons or resting on beacons or buoys. The adult is dark chocolate-brown on the upper-parts and breast, white on the abdomen, underwing and under-tail coverts. The bill is pale bluish or yellowish, with greenish-yellow on the skin of the face. The legs, feet and webs are also greenish-yellow.

The Brown Booby eats a variety of herring-like fish, or fish that are similar in habits to the herring. To get its food it dives from a considerable height and often pursues its prey under the water; it has been caught in fishermen's nets at a depth of as much as 90 feet.

It is a ground-nesting bird and builds a rough structure of twigs and seaweed. Two eggs are usually laid but only one chick is raised. The eggs are large and pale blue, covered with a white chalky layer which can be scratched off. The young bird is fed on partly digested fish by thrusting its bill and head into the throat of the parent. The nesting season is about March to August. No breeding places are known in the Gilbert and Ellice groups. Fanning, Christmas Island, Canton and other Phoenix Islands are known to have nesting colonies.

About thirty birds were roosting on the tops of coconut palms at Numatong (Nonouti) in June but there was no evidence that they nest there. One of my native companions climbed a palm at night and caught one of

these, which we measured. While roosting or breeding these birds, which are usually silent, utter loud quacks and honking noises. Mr. G. B. Gallagher, a British District Officer who died at Gardner Island in 1941, had a tame booby he called "Honk".

11. Sula dactylatra personata. Blue-Faced Booby. (Masked Gannet)

Kena. (Loka) Mouakena.

The Blue-faced Booby is seldom seen in the Gilbert and Ellice groups; an occasional one is picked up by parties out bonito-fishing in the ocean; Kennedy saw only one in five years at Vaitupu. They are fairly common on Christmas Island, rare on Fanning and Washington, and present in small numbers on Canton, McKean, Gardner, Phoenix and Sydney of the Phoenix group.

The adult is a large white bird with contrasting dark brown primaries and tail feathers. The bill has a horn-coloured tip, the base being orange-yellow in males and pinkish in females; the feet are olive-drab in males and lead-grey in females. There is a conspicuous patch of dark blue skin on the face and throat. Although the colouring is similar to that of some individuals of the Red-footed species it may be distinguished from the latter by the fact that the feet are never red; also a smaller area of the wings is brown, and it never nests in trees.

The Blue-faced Booby nests on the ground, a shallow depression in the sand, without other materials, forming the nest; two eggs are laid but only one chick is raised. The nesting season lasts from about April to December in different localities.

Its feeding habits are different from those of other boobies, for it lives almost entirely on flying-fish, which it seizes at the surface of the water or even in the air.

12. Sula sula (rubripes?): Red-footed Booby.

Tapuku. (Talanga?) Keta. (Makitaba)

The Red-footed Booby differs from the other two species in its nesting and feeding habits. It lives mainly on squid which it catches in the twilight of early morning and evening when squids and other creatures from the ocean depths come to the surface.

It is one of the few tree-nesting boobies of the world, and builds a rough nest of dry twigs; at Canton these are mainly on Scaevola bushes; at Christmas Island on Tournefortia, and at Gardner on Pisonia. Large nesting colonies have been reported at Fanning and Washington, and smaller colonies on most of the Phoenix Islands. There is a possible nesting site at Bakatorotoro (Abaiang) in the Gilberts. A young nestling in white down shown to me at Tabuarorae (Onotoa) in August, 1955, was found on the broken

trunk of a Pisonia, and appeared to be of this species. No other nests were found and it was probably an isolated case. These birds are also said to roost but not nest on Pisonia trees on the islets of Tenon and Namauri at Tabiteuea. There was no sign of them there in January, 1956.

Only one egg is laid and the young birds, like those of other boobies, are covered with a coat of thick white down for several months. The nesting season is from April to December in different localities; the eggs are similar in appearance to those of the Brown Booby.

Measurements, colourings and classification are discussed at some length by Murphy et al. in the booklet "Canton Island"; it appears that the birds in this region are smaller than those elsewhere, possibly warranting a new subspecific name to distinguish them from S. s. rubripes. Further measurements are needed on birds from these islands other than Canton.

III. FREGATIDAE (FRIGATE-BIRDS).

These pirates of the Pacific skies are well-known throughout the Colony; nearly every island has a few birds soaring over the land or surrounding ocean during the day, and resting on the palm-tops or other tall trees at night. When one comes to find where they nest, however, it is a different story, and many wild rumours are told. I was not able to find for certain a single nesting-site in the Gilbert and Ellice groups; also no males with the characteristic red inflated gular pouches were observed in that region, although I was told that occasionally one such is seen. There are, however, plenty of birds of various ages - all flying of course. Immature males are common.

Frigates are the largest birds seen in the Colony, fully grown ones having wing-spans of six to seven feet. Of the five species in the world, two occur here, and their identification is difficult except in mature adults. They inhabit windy situations for if grounded in a sheltered position they are helpless and unable to rise into the air. During violent westerly storms in the Ellice Islands an occasional frigate would reach us on the beach on the sheltered lagoon side and was unable to do anything more elegant than flap clumsily along the beach with its wingtips hitting the sand. Also for this reason, nesting and roosting sites are in exposed places, and tame birds are usually kept on elevated perches on the windward side of the atolls.

The long forked tails of these birds are sometimes not apparent when in flight. If angered or disturbed the birds snap their tails in a scissor-like fashion. The legs are very short and, although the feet are partly webbed, they seldom rest on the water. Personally I have never seen one do so but then I have not lived for any length of time among a large colony. According to the report by Degener and Gillaspy one of them saw "a small flock of frigates playfully land, float and rise again from the placid waters of the lagoon". From my own experiences, the word'placid' used here is puzzling - surely the incessant trade wind of Canton was necessary for the birds to take off. The bill is long and slender with a sharp hook at the tip; when annoyed the birds have a curious habit of rattling the

bill. On the throat there is a patch of skin which, in mature males, can be inflated with air to form a large red balloon (gular pouch) in the breeding season.

Their food consists of flying-fish, other small fish, jellyfish, molluscs and other creatures picked up from the surface with a swift movement of the bill when they are in flight; more often, however, they pursue noddies, boobies and terns and force them to give up some of the food they have swallowed, which is then usually caught by the frigate-bird before it reaches the water. It is this habit which has earned them the nickname of 'man-o'-war hawk'. When other species are returning home in the evening the frigates descend from their lofty soarings and pester the smaller birds until a meal is consumed. In the Gilbert and Ellice groups the noddies are the commonest victims, while at Canton and some other islands boobies are the ones most attacked.

Their nests are clumsy structures of twigs, placed on low bushes or trees, or sometimes on the ground in windy situations. Although a single large egg is usual, Lister observed a few nests containing two on Phoenix Island. Both parents share the incubation; if the nest is neglected other frigates will rob the sticks, or egg, or kill the youngster. Immatures can always be distinguished by their white or rusty-coloured heads, and it is probably at least two years before adult plumage is attained. Females are larger than males.

In some Pacific territories frigates have been used as message-carriers from one island to another, and there is one genuine story of a strange frigate which was caught by an Arorae man who attached a note to its wing and released it; the bird returned to its owner who was at Ocean Island, about 450 miles away; the Arorae man later received a letter of thanks for returning the bird. Since there appear to be no breeding colonies in the Gilbert and Ellice groups the frigates seen there must all cover at least several hundred miles in their flights from the Phoenix colonies.

The long primary feathers are used in the Gilbertese game of "Kabane", in which a model 'bird' is catapulted vertically into the air while, from twenty yards or so away, the 'hunter' attempts to bring down the bird with a slingstone weighing 7 oz. attached to 25-30 fathoms of line. Now used only as a game, the pastime was formerly a practice for the actual attempts on the soaring birds. Also in the old days canoe crests of certain clans were made of the primary feathers of frigates. In order to tame the birds some natives use special diets, such as a particular species of small fish, or boiled abdomens of hermit crabs. Others, when feeding the bird, add some of their personal hair-oil to the food and rub some oil on its bill; in this way they claim the bird can recognise its own master.

13. Fregata minor palmerstoni. — Greater Frigate-Bird (Pacific Frigate-Bird)

Katafa. (Manulasi) — Eitei.

Males are called Marenaiti or Bairakau; or, when the red gular pouch is showing, Koko or Tarakura (Ellice: Talakula or Katokula); females are

called Ubamara or Ubaimoa, and young birds Ubaitoi or Ubamei (Ellice: Upaitoi).

The adult male is dark brown to black all over, with a bluish-grey bill and black, brown or pink feet. It is the darkest bird of either species and is thus easily identified. The female has a dark brown or blackish head, neck, upperparts and abdomen, but the throat and breast are white. Immatures have white or rusty coloured heads and patches of white on the breast and abdomen; by the shape of these patches it is usually possible to tell whether the bird is male or female.

Canton and other Phoenix Islands, and the Line Islands, are known breeding places. The nesting season is an extended one and lasts at least from March to September. A large flock of an estimated 200 birds rested on Pisonia trees at Tabuarorae (Onotoa) but there was no sign of nesting there; these were observed coming in to roost in the evening twilight only, and could have been of the species F. ariel.

14. Fregata ariel ariel. Lesser Frigate-Bird.

Katafa. Eitei.

Not many islanders can distinguish this bird from its near relative described above, and it is difficult to identify females and young birds, which are similar in markings to those of F. minor. However the male is easy to distinguish from below as it has a white ventral side patch under each wing, the remainder being dark brown to black. The white on the breast of the female extends back under each wing corresponding roughly to the side patches of the male; this is about the only easy way of distinguishing it from a distance from F. minor female. All are smaller birds than F. minor.

It is not so common as the Greater, but I have seen a few at Nonouti, Funafuti and Nukufetau, and possibly the flock mentioned above at Onotoa. Moul reported them from Onotoa. The only nesting place reported in the Colony is the large one observed by Lister in 1889 on Phoenix Island.* Thousands of nests on the ground with eggs but no young were observed in June. Although they have been seen at Canton Buddle concluded that they do not breed there.

IV. PHAETHONTIDAE (TROPIC-BIRDS OR BO'SUN BIRDS)

This family is represented by only three species in the world, of which two occur in this Colony. With their delicate plumage colouring and unusual median tail-streamers, they are among the most beautiful of sea-birds. The plumage is mainly white, with a roseate tinge ventrally, and a few black markings; the black bar through the eye is a prominent feature. They have long wings, thick straight bills, and short legs with all four toes webbed. They are diving birds, feeding chiefly upon fish and squids.

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* Bird listed as F. minor but Lister's detailed description (1891) fits F. ariel.-Ed.

A single bird or a pair is often encountered at sea, when they will circle around the ship for lengthy periods, occasionally uttering a shrill rasping cry. The flight is somewhat undulating with the wings beating constantly and steadily something after the manner of pigeons. I have not seen them settle on the water although it is said they occasionally do so.

15. Phaethon rubricauda melanorhynchos. Red-tailed Tropic-bird.

Tavaketoto. Taake.

There now seem to be no definite nesting places for these birds in the Gilbert and Ellice groups; there was once a considerable colony at Nui on an islet called Bikentaake (= "Island of the Tropic-bird"), but the birds have not returned there for many years. The chief breeding places are now in the Phoenix and Line Islands; known colonies occur on Gardner, Hull, Phoenix, McKean, Sydney, Canton and Christmas, and rarely on Fanning. Nests are situated on the ground under saltbushes (Scaevola) or other small shrubs, or between rocks or under overhanging rocks; a few dead leaves are all that go to make the nest. Only one egg is laid, it being reddish-brown in ground colour and beautifully marked with larger blotches and streaks of purplish-black. Nesting lasts from May to November. Both young and adult birds protest loudly if the nest is approached, and will often strike with their stout bills.

The newly hatched young are thickly covered with white down; later some black markings and bars appear on the back and wings; in adults these have disappeared except for a small patch on the wings and flanks, so that the plumage is chiefly white, often tinged with rosy pink or salmon shades. There is a characteristic black streak curling through each eye, and the shafts of the primary and tail feathers are black. There are 14 white tail feathers and the two median red streamers from which the bird is named. The bill is usually an orange or vermilion shade, with a black streak through the nostrils; the legs and bases of the toes are pale blue, and the rest of the feet black.

The red tail feathers are obtained merely by pulling them out; they were much sought after in the last century by milliners, and in earlier times were worn in some islands of Polynesia as a sign of chieftainship. Of three red tail-streamers which I was given from Christmas Island the longest measures 18.2 inches. For some of the village prophets in the Gilberts the appearance of this bird signified good luck, but for others approaching death in the clan; it is thus apparent that the species has never been common there.

16. Phaethon lepturus dorotheae. White-tailed Tropic-bird.

Tavake. Ngutu.
(Tavakepuka; Tavakelau) (Koroangutungutu; Tarangotu)

This bird may easily be distinguished from the Red-tailed species by its two long central tail-streamers, which are pure white and not as narrow as the red ones. The next adjacent feathers are also fairly long

and there are 8 shorter tail feathers, making 12 in all. There is more black on the wings and flanks, with the rest of the plumage mainly white, with or without the roseate tinge; the black eyestreaks are not so heavy. The bill is yellowish, base greyish; the legs and bases of the toes are yellowish or flesh-colour and the rest of the feet black.

These birds nest high up on Pisonia trees (called 'puka' in the Ellice), or on the clumps of epiphytic ferns which often occur well up on the trunks of coconut palms in the relatively high rainfall belt in the Ellice. On Fanning and Washington the favourite nesting site is said to be the top of a tall coconut stump. (According to Kirby the former owner of Christmas Is., Father Rougier, accounted for its absence there by the lack of crownless coconut trunks.) Other known nesting places are at Vaitupu, Meang (Nui), Lafanga (Nukufetau), and Gardner Island. Two eggs are laid and the nesting season extends from about November to April. The eggs and young are similar to those of the Red-tailed, and immatures of the two species are difficult to distinguish until the long tail feathers develop.

V. PROCELLARIIDAE (SHEARWATERS AND PETRELS)

The shearwaters earned the name from their habit of skimming low over the waves, with one wingtip almost touching the water, in search of food, which consists of fish, squids, crustaceans and other pelagic marine creatures; they often follow the ship in search of scraps of food, either thrown overboard or disturbed by the turbulence of the propellors. In the region of the trade winds they glide effortlessly over the wave-crests with hardly a wingbeat, and one is constantly amazed at their ability to stay airborne. Equally amazing is their sudden appearance and disappearance from the vicinity of the ship; they never approach very close, and their identification at sea is notoriously difficult. They are all rather dull-coloured birds of some scheme of blacks, browns, greys and whites. The bills are strong and sharply hooked at the tip, those of the petrels being relatively shorter and stouter than those of shearwaters. The feet are webbed, and they sometimes settle on the water and swim about while feeding or resting.

Only five members of the family are resident in the Colony, and none of these is well-known in the Gilbert and Ellice groups, being but occasional visitors encountered at sea. Their breeding places are found in the Phoenix and Line Islands, especially at Canton and Christmas Island. They spend nearly all their time at sea, and on land their legs are hardly strong enough to support them, so that they often shuffle along on their breasts with the help of their wings.

17. Puffinus pacificus chlororhynchus. Wedge-tailed Shearwater.

Kumala. Korobaro.

This is a large dark bird with upperparts dark chocolate-brown, blackish on the primaries and tail. The tail is rather long and wedge-shaped. The underparts undergo colour phases during the year so that

sometimes they are greyish-brown, and sometimes white. The bill is pinkish with a darker tip, and the feet are yellowish flesh colour or whitish.

Breeding places have been reported at Canton, McKean, and Christmas; the nesting season lasts from May to August. The nests are in burrows beneath soft soil or sand, often five feet or more in length, the nest proper being a mere hollow at the end and sometimes lined with a few bits of grass or feathers. One white egg forms the clutch. There is much flying about and activity over nesting places at night and both male and female parents take turns at incubation. The young are fed on an oily food which is regurgitated by the parent, and they become very fat and often larger than the parents. The parents leave the young before they can fly properly, and this store of fat keeps them alive until they are able to leave the burrow and head off to sea. At night low wails and moans rend the air over the breeding grounds as the sitting parents welcome their mates returning from the ocean.

18. Puffinus nativitatis. Christmas Island Shearwater

? Tinebu.

The colouring is similar to the dark phase of P. pacificus, but the bird is smaller and has a black bill and feet. The calls are said to be more of a barking or "humphing" nature than the mournful wailing of the Wedge-tailed. Breeding places are known at Christmas Island, Canton and Phoenix Island. Nesting occurs from May to December on the surface of the ground, under bushes or in a crevice among rocks.

19. Puffinus lherminieri dichrous. Dusky Shearwater. (Audubon's Shearwater)

Tapuku. Nna.

This is the smallest of the local shearwaters; it is dark sooty brownish-black above, with white underparts. The under tail-coverts are black and the sides of the breast grey. The bill is short and black, with the feet flesh or yellowish.

They nest in burrows excavated in the sand, from about July to September. P. dichrous was described from McKean by Finsch and Hartlaub (1867) from a specimen collected by Gräffe. Alexander records them from Christmas Island but King does not include them in his list from there. Bailey and others observed burrows on Canton in May and June.

20. Pterodroma alba. Phoenix Petrel.

Lulu. Tangiuoua. (Ruru; kuma)

Comparable in size or a little smaller than Christmas I. Shearwater (14 inches according to Mayr).

Called the "kuma" at Nui, this bird is more commonly known as the "tangiuoua", meaning "two cries", because of the two different kinds of sounds which it makes: one is a high-pitched warbling cry and the other a low bubbling or gurgling sound. There is a belief among some Gilbertese that if the cry of this bird is heard above someone's house during the night there will be a death in that family in the near future.

It is probable that the species was more well-known in the Gilbert and Ellice groups many years ago than it is today, and there now appear to be no nesting places in those groups, and not many of the younger people have seen the bird. The nesting season seems to be a prolonged one; eggs have been found at Christmas Island from June to February. Other breeding colonies are at Canton, Phoenix Island, and possibly Gardner. One white egg is laid, usually on the surface of the ground under clumps of vegetation, or occasionally in shallow burrows.

The adults are most active at night, and in the late afternoon and evening. They are sooty black above with a dark band across the upper breast, and dark underwings. The throat, lower breast and abdomen are white; the bill is black, and the feet yellow with the ends of the webs black.

21. Nesofregetta albigularis. White-throated Storm-petrel.

? Bwebwe-ni-marawa.

Storm-petrels are the smallest of the seabirds, the above species being only about 8 inches in length. It has long legs and webbed feet, the legs (tarsi) and toes being remarkably flattened laterally, and the legs so long that they extend beyond the tail in flight. Except during the breeding season and when blown ashore by storms, all their time is spent at sea, and on land they are unable to walk and have to use their wings to help them shuffle along on their breasts. At sea they sometimes seem to pat the surface with their feet to assist the skipping movements in search of food, so that they seem to be walking on the water. Occasionally they rest at sea. The food consists of shrimplike creatures and other tiny animals from the surface of the ocean. They often fly in groups across the waves, with a jerky, erratic flight which has led some people to believe they are large butterflies - the Gilbertese name means "butterflies of the ocean".

The adult is sooty-black to greyish-black above with a noticeable white patch across the rump, and a sooty band across the breast; the throat, lower breast and abdomen are white, and the underwings smoky-white; the tail is long and deeply forked, and the bill black.

In the breeding season they make burrows in the soft soil or under bushes or among rocks; a single egg is laid, creamy-white in colour, with small reddish-brown and faint purplish spots, more dense at the wider end. Both male and female take turns at incubation. Breeding colonies are quiet during the day but very noisy at night when the birds from the sea return to relieve their mates. The young bird is fed disgorged oily food from the parent and, like the young of Shearwaters, grows bigger than the parents, who desert it before it can fly.

Eggs have been found in July on Phoenix Island (Lister), and in December on Christmas Island (King). No other breeding places in the Colony have been reported. Two birds seen near the ship between Tarawa and Ocean Island in January, 1956, were certainly of this species, the long legs and white rump-patch being prominent. This suggests a very wide feeding-range if the Phoenix Islands, nearly 1000 miles East, are the nearest nesting places.

VI. ARDEIDAE (HERONS)

22. Demigretta sacra: Reef Heron.

Matuku. Kaai.

The Reef Heron is the only wading bird which is permanently resident in the Colony. Often mistakenly called a crane or stork, it is one of the most conspicuous birds of the beaches and reefs; hunting small fish in the shallows and tide pools, or flying with great slow beats of its broad wings over the lagoon it is a graceful and attractive bird. There are three colour phases: pure white, greyish-blue, and a third chiefly white but mottled in varying degrees with the blue-grey feathers; local names for the three types are:

White Heron:	Matuku kena.	Kaaimatang.
Blue Heron:	Matuku uli.	Kaaibuaraku.
Spotted Heron:	Matuku pulepule.	Kaaimakin.

In each kind the legs and feet are yellowish-green, or dull olive green, and the bill is dull orange, often marked with blackish or purple on the upper mandible. It was more difficult than it at first appeared to count the relative numbers of the three phases along a stretch of ocean reef at low tide, not only because of the movements of the birds, but also because the Blue Herons were so much better camouflaged against the dead reef coral-heads; my estimates were that the ratio of Blues to Whites was about 2:1, with the mottled variety present to the extent of about one in every 10 birds. (These observations were for Tarawa, the ratios on other islands not necessarily being the same.)

The long neck and legs are used to good advantage when wading in the shallow waters on the reef or lagoon in search of food, which consists chiefly of small fish and crustaceans of many varieties, often brightly-coloured; quite often a bird will be seen chasing a lizard (Emoia cyanurum) along the land vegetation, or hunting worms, insects and small fish in the babai pits; another habit is that of drinking the 'toddy' (flower sap from the bound spathe of a coconut palm) from a hanging cup or coconut shell high up on the palms. Usually a single bird or a pair is seen in one territory, but at high tide there may be a gathering of ten or more in some quiet spot among bushes along the shore, or on the low branches of a mangrove thicket.

In the Colony the bird is a familiar sight on all islands of the Gilbert and Ellice groups, but surprisingly is not seen in the Phoenix and

Line Islands. The nesting season lasts from November to June. A rough platform of sticks and dry twigs or rootlets comprises the nest, which is normally situated on high coconut or pandanus trees; one nest at Onotoa was, however, only four feet from the ground, in an 'uri' tree (Guettarda speciosa). Two or three pale greenish-blue eggs form the clutch, and the nestlings are very ugly and awkward for many weeks. Immatures which have just left the nest have weak legs, rather untidy feathers, and are not able to fly more than a few yards at a stretch; their natural ability as fishermen is, however, well developed. The feathers, particularly of the white phase, are often used for decorative purposes in fans and other handicrafts. A gutteral call is heard, mainly from nesting adults.

VII. COLUMBIDAE (PIGEONS AND DOVES)

23. Ducula pacifica pacifica. Pacific Pigeon.

Lupe. Rube.

Although common throughout most of the Pacific, this large pigeon is found in the Colony only in the Ellice group. (A few semi-tame birds have been taken as pets to some islands in the Gilberts.) In the Ellice they are uncommon at Niutao and Funafuti, fairly plentiful at Nui and Vaitupu, and present in small numbers on all the other islands. According to Whitmee this is a smaller bird than the Samoan race; total length is about 15 inches.

The upper wings and back are grey with a greenish sheen and some brownish tints; the head, neck and underparts are light pearly grey, with pinkish tints on the underparts; the under tail-coverts are deep reddish-brown, and the underwings grey. The bill is dark grey to black, and there is a characteristic large soft operculum or cere at the base. The feet are bright coral red.

Berries of various trees are the favourite food, common ones eaten being 'uri' (Guettarda speciosa),'bero' (Ficus), and 'mao' (Scaevola). They are also known to eat ripe breadfruit from the tree, and, like the herons, will be seen drinking the toddy from a hanging shell. The call is a deep cooing, something like "pr-rrr-ooo-oo".

Nests are usually built high on coconut palms at the bases of the petioles; at Nanumanga in the Ellice they are said to nest on mangrove shrubs. Two oval white eggs are laid, and the season lasts from about June to September.

24. Gallicolumba erythroptera: Ground Dove.

Lupe palangi. Bitin.
(Taobe)

While Ducula is a native in the Ellice, being referred to in many old songs and legends, the ground doves are undoubtedly recent introductions of the present century, probably mainly from Fiji. At Abemama they are

reported to have been introduced from Nauru about 20 years ago, and have multiplied considerably so that there is now a fair number in a wild state A few pairs have also been taken from Abemama to some other Gilbert Islands as pets, but in most of the Colony they are unknown. A pair taken to Nonouti had four offspring, and in June two females had nests about ten feet off the ground in an old deserted house; the nests were of grass and straw and built inside old boxes; each contained two eggs, oval in shape and creamy-white in colour. At Abemama they are said to nest in coconut crowns, often high above the ground. They feed mainly on the ground; when disturbed they fly up into the palms and their call, a soft "coo", may then be heard.

The colouring is typically darkish greys and white; the head, neck, back and upper breast are grey with a purplish and greenish sheen or irridescence; the secondary wing feathers are mainly dark grey and the primaries and tail feathers mainly white; the abdomen is white, often speckled with grey, and the under tail-coverts white. The short bill is dark grey with a small whitish operculum at the base; the legs and feet are coral red, or purplish red. Some birds have less white than others, and hardly any two are exactly alike.

25. Gallicolumba stairii. Friendly Ground Dove.

There are a few individuals in a semi-wild state at Abemama, probably of this species, and probably introduced from Fiji where it is common. The habits are similar to those of G. erythroptera, and there is no distinction in vernacular names of the two species.

The colouring is mainly brown with a little white on the wings and lower breast; the upperparts have a greenish sheen in some lights. The bill is dark and the feet deep red or purplish red.

VIII. PHASIANIDAE (QUAILS AND PHEASANTS)

26. Gallus gallus: Jungle Fowl.
(Domestic Fowl)

Moa. Moa.

These semi-domesticated chickens are common on all islands where there are native villages, although the people themselves seldom eat them or their eggs; they are however freedly offerred to visitors and Europeans during feasts, and for barter. Both the birds and the eggs are smaller than common domestic fowl of European countries, being much inbred with various imported strains. Exceptionally wild ones are sometimes encountered in thick undergrowth of neglected coconut plantations, and these can fly considerable distances. There is no one characteristic colouring, although the roosters tend to be more uniform in colour than the hens. They are fed in the open on scraps of any food, particularly fish and grated coconut; normally no enclosure is kept especially for them by native families, but local European families invariably maintain a well-stocked 'chicken-run'. It is also locally held that they do not lay well without regular supplies of fish or crab. In most cases a whole dressed chicken is not too large

for one person's meal. Once during an inspection tour of village schools at Onotoa I was given whole chickens roasted in the native earth ovens three times in the one day! When children brought in large numbers of eggs from the nests of feral chickens in the 'bush' we tested them before bartering, as a goodly proportion would always be addled. As with other birds, the feathers are used for handicraft decorations.

IX. SYLVIIDAE (WARBLERS)

27. Conopoderas aequinoctialis. Warbler.

? Bokikokiko.

This is the bird commonly referred to as the 'Christmas Island canary'. It is probably the smallest bird in the Colony, the subspecies at Christmas being only about 5 inches in length; this is C.a. aequinoctialis. At Fanning there is a similarly coloured but definitely larger race called C.a. pistor, while at Washington Island further northwest still, there is a record of a similar bird which seems to be of a race intermediate in size to these two.

The upper parts are greyish with whitish tips to the feathers; the underparts are mostly whitish, tinged with pale grey on the sides and with pale yellow on the breast; the legs and feet are grey, and the bill blackish above, flesh colour below.

On Christmas they live chiefly among 'ren' bushes (Tournefortia); the food consists chiefly of flies and beetles caught on the branches and leaves, on the ground and in the air. Nests are made in forks of the 'ren' bushes; the nest often consists of strands of the parasitic creeper called 'te ntanini' (Cassytha) coiled around the outside and lined with leaves and grasses. It is said that two or three small eggs are laid about June; the colouring is whitish with reddish-brown spots.

Although both Kirby and King list the Gilbertese name as 'kokikokiko' I have not spoken to any Gilbertese native worker from Christmas Island who has referred to it other than 'bokikokiko'.

X. PSITTACIDAE (PARROTS)

28. Vini Kuhlii. Parakeet.

? Kura.

This very pretty bird is common on Fanning and Washington, but has not been reported from Christmas. It is about 7 inches long; the forehead

and crown are green; back of head and neck dark blue; back olive-green to yellowish-green at the tail; underparts red, with purple on the abdomen, and yellowish-green under the tail; wings greenish above, blackish below; bill and feet red.

It is said to lay two eggs in hollow places such as the tops of old coconut stumps, and, according to one oral report, it will sometimes carry its eggs away to another site if disturbed.

PART B: MIGRATORY BIRDS.

With the exception of the Long-tailed Cuckoo, all the migratory birds which visit these islands normally nest in the northern hemisphere; of these the Arctic waders of Alaska and Siberia easily form the most important group. Most of these birds leave the Colony for their northern breeding grounds about March or April and return south again, after the short Arctic summer, in September and October. Allowing for travelling time each way across some six thousand miles of ocean it is obvious that their nesting season is a comparatively short one - about June to August - and yet during this brief period they manage to prepare nests, lay and hatch the eggs, and feed the young until they are strong enough to accompany their parents on the southern migration.

Most of the migrants seen here also occur in other island territories of the north-central Pacific - Hawaii, the Marshalls and the Carolines - and some birds, such as the Turnstone and Godwit, even reach as far south as New Zealand every year, another three thousand miles on each leg of the journey. How fast do they travel? No accurate figures are available but, from records of migratory birds in Europe, the average speed for waders is 150 to 200 miles a day; here in the Pacific across certain routes in the central ocean (what Baker calls the "Nearctic-Hawaiian Flyway") there are few resting places, and probably greater average speeds are achieved. Do they ever rest on the ocean? Bailey, in "Birds of Midway and Laysan", quotes an observer who watched Golden Plovers alight on the water several times (in 1891). What percentage survives the migration? There are many unsolved

problems which can only be answered by banding and careful observations over long periods. The birds are noticeably thin on arrival in the Colony, but are correspondingly plump and often showing the brighter hues of breeding plumage before leaving for north again.

I have on occasion observed what appeared to be the arrival or departure of some of these species. The Godwits were particularly thin and pale and arrived on the lagoon mudflats in flocks of 30 to 50 birds, which immediately sat down without any preliminary strutting about! (Normally waders hardly ever sit, although they often rest on one leg.) On other occasions during the 'locally-resident' phase, this apparent state of exhaustion was never witnessed. A flock of about 200 Golden Plovers was seen to depart north from one of the old wartime airfields at Tarawa on April 4th, 1955. Many of these birds were in the darker breeding plumage and they had been observed congregating here for several days. There was much restlessness and chattering and wheeling-about for a few yards every day before they finally disappeared into the northern sky. The flying height seemed to be not much above the coconut trees, i.e. say, 100 to 200 feet.

An interesting point about the Godwits, which distinguishes their movements from those of other Arctic waders, is that they certainly _pass through_ these islands in large numbers but only a few actually stay for the summer here. There is thus a pronounced increase in numbers on both the southern and northern journeys; their comparative scarcity between migrations probably accounts for the fact that many Gilbertese to whom I described the birds could not recollect having seen it at all! I have, however, recorded it on all islands visited in the Gilbert group. As with other species listed below, a few non-breeding birds may be seen in the Colony during the northern summer.

With the Plovers it was noticeable how a single bird or a pair seemed to occupy the same territory each season; one sensed that they were the same birds returned each year but, of course, there could be no proof of this without marking in some way. However, Gilbertese who have caught Turnstones for some of their games, and have identified their own birds by tying a piece of coloured cloth to a wing, have had the same birds return to them after an absence on migration, presumably to the Arctic and back.

I. CHARADRIIDAE (TURNSTONES AND PLOVERS)

29. _Arenaria interpres interpres._ Turnstone. (Sea Dotterel)

Kolili. Kitiba.

Seen in all islands of the Colony, the Turnstone is the commonest of the Arctic visitors, and is so named because of its habit of busily overturning stones, seaweeds and tidal debris on the reef and beach in search of small crabs, shrimps, sandhoppers, and other marine creatures. Occasionally larger organisms such as the grey sand-crabs or ghost-crabs (_Ocypode_ sp.) with carapaces up to two inches across were observed being caught and eaten. Bailey states that on Midway they feed heavily on saltbush (_Scaevola_)

berries. In olden days the Gilbertese used to trap Turnstones for games and bird-fighting; one of their traps consisted of an unhusked half coconut with food inside the kernel and slip-nooses of fine coconut fibre fixed vertically in the husk. Another had similar nooses set into a ring of coconut midrib which was laid on the beach with bait inside. Quite heavy stones can be lifted with their strong bills. The body is plump with a short neck and short orange legs. They are very sociable birds, usually being seen in groups of ten to 100 or more, moving about with quick short runs in a very businesslike manner. When in flight broad white bands across the upper wings and down the back are visible.

In summer plumage some of the upperparts turn reddish-brown, but the winter coat is a scheme of greys and whites. They fly north in late April and return about October. Their nests (in Arctic regions) are mere holes between tufts of moss, sometimes lined with grass or reindeer hair. Four eggs are laid in June and the young birds are ready to fly south by the end of August. The breeding range is circumpolar.

30. Pluvialis dominica fulva. Pacific Golden Plover.

Tuli. Kun.

The Golden Plover is also a common bird; although a few may be seen all the year round the greatest numbers are present from October to April. There is a marked difference between summer and winter plumages; in October and November when the birds arrive from the north they are noticeably thin after the long journey, and pale in colour, the underparts being almost white; by April, however, they are plump and show conspicuous black breasts with a very pale stripe over the eye and down the sides of the neck and body. The upper wings, back and tail are darkish brown mottled and edged with fawn and golden yellow. The bill is dark grey, about 1 inch long; the legs are long and slender, light bluish-grey in colour; there are only three toes.

Winter plumage:	Ellice:	tuli.	Gilbertese:	kun au meang.
Summer plumage:		tuli alo malala.		kun au maiaki.

Note: au meang: (literally: northern season) is the Gilbertese 'winter' or stormy season, about October to March, which starts when Nei Auti (the cluster of the Pleiades in the constellation Taurus) begins to show above the northern horizon at 6 o'clock in the evening, and the sun moves south of the celestial equator. Irregular storms and winds, often from the west, more frequent rain, and strong ocean currents flowing westerly characterize this season, which is the period when Arctic waders are common.

au maiaki: (lit: southern season) is the Gilbertese 'summer' or settled season, about April to September, which starts when Rimwimata (the big red star Antares in the constellation of the Scorpion) begins to show above the southern horizon at 6 o'clock in the evening, and the sun moves north of the celestial equator. Steady easterly trade winds, blue skies, little rain, and weaker ocean currents flowing easterly are typical of this season, which is also the period when Arctic waders are scarce.

The Plover is a friendly little bird, not easily frightened, and one can approach to within a few yards; on the wing it is seen to have a surprisingly long wing-span, about 18-20 inches, and is a strong flyer. Sometimes when approached it displays the curious habit of stretching its head up every now and then. Some Gilbertese have a game of asking the Plover whether it's going to rain soon, or whether the ship is near - if it stretches its head up in answer, that means 'yes'. Several different calls may be heard, common ones being like "whee-oo-wit", and "tu-li".

The food consists chiefly of small crustaceans and other tidbits found on the tidal flats or near the water's edge on the beach; often, however, birds will be found in open grassy areas or among the coconut clearings, where they can be observed eating insects and sometimes small skinks. During the heat of the day they are often more common among the coconut trees than on the beaches. There were usually twenty or more scattered over the school football field at Bikenibeu, Tarawa, always singly or in pairs. They are not at all sociable until near the departure times for migration, and one bird or a pair will defend the feeding territory, and savagely attack any intruders, even to the extent of pulling out a few feathers. They occur on all islands, including the Phoenix and Line Islands.

II. SCOLOPACIDAE (TATTLERS, CURLEWS, GODWITS)

31. Heteroscelus incanus incanus. Wandering Tattler.

Litai. Kiriri.
(Kapo; Kilikilitai;
Vivitai; Tulitainamo)

Variously named in different Ellice Islands, this bird has but one Gilbertese name which is adapted from its common cry when alarmed, a rippling 'ki-ree-ree', sometimes repeated once or twice. It is a very inconspicuous bird when sheltering among the rocks and dead coral along the coasts at high tide, the greys of its plumage harmonising exceedingly well with its surroundings. However, as its English name "Tattler" suggests, it is easily frightened and takes to flight uttering the characteristic warning cry at a shrill pitch and thereby setting other birds on the alert.

The bird is dark grey above and has soft bluish-grey wavy lines on a pale grey or whitish background on the underparts; the bill is fairly long, straight and dark grey, while the legs are dull yellow. There is a conspicuous light superciliary streak and a dark grey eye streak from the base of the bill.

It generally feeds alone on the edge of the tide or on mud flats but often wades out into shallow water in search of food; at high tide larger groups rest together among the rocks or in the shade of mangrove bushes. On one occasion a Tattler was observed perching on a high coconut frond, and when frightened off it flew back to another coconut tree.

In the Ellice the cry of the Tattler in the evening is regarded by the tautai (fishing-captains) as a good omen for the catching of bonito (Euthynnus yaito) the next day. Tattlers are well-known on all islands; they leave about April for the northern breeding grounds, where they nest on gravel bars in Alaska; the eggs are so well camouflaged that only two nests have been found, one in 1923 and another in 1939.

32. Heteroscelus incanus brevipes. Grey-tailed Tattler.
(Asiatic Tattler)

No distinct vernacular names exist for this closely related race, which appears to be but an occasional visitor to these islands. The two are barely distinguishable in winter plumage in the field. The upperparts tend to be slightly lighter grey, and not so uniform in colour; also the nasal groove is somewhat shorter, and the wingspan slightly smaller. In breeding plumage the barring on the underparts is less pronounced and does not cover the lower belly and under tail-coverts. They appear to have similar habits to H.i. incanus, except that the call is different, being a kind of "ki-leep", very shrilly and repeated several times, the second note being higher in pitch. These were closely observed only at Tarawa, but may occur elsewhere.

33. Numenius tahitiensis. Bristle-thighed Curlew.

Founga. Kewe.
(Kove)

Largest of the migratory waders, this handsome bird is easily recognised not only by its size but also by the very long curved bill and haunting cry from which its Gilbertese name is derived. (The listing of the Whimbrel, N. phaeopus variegatus by Moul at Onotoa appears to be a mis-identification; it is possible that an occasional Whimbrel will be seen in the Colony, although not recorded by the present writer as no birds were shot for specimens; they are somewhat similar to Curlews in the field; the Curlew, however, may be distinguished by its characteristic cry, much longer bill, bolder colouring with more rufous tinges, darker axillaries and slightly larger size - I have confirmed all these features from observations as close as 15 yards, with careful stalking as the birds are wary and easily frightened.)

Occasional birds may be seen on all islands at any time of the year but are most common from about late August to April or May when they leave again for their breeding grounds in Western Alaska; the first nests were not discovered till 1948 - they are mere hollows in the tundra moss; four eggs are usually laid, dull greenish-buff in ground colour with grey and brown markings.

Adults have the upperparts speckled with light and dark browns; the underparts are pale buff, almost white under the tail; the plumage has a distinct rufous tinge, and in summer breeding dress the males have stronger reddish-brown on the neck and breast. There is a pale line along the mid-crown and another above each eye, and a dark brown line through each eye,

so that the head has a very striped appearance; the bill is pinkish at the base fading to grey towards the tip, curved strongly downwards and 4-5 inches long; the legs are long, steely blue-grey in colour, and there is a short hind toe.

Curlews hunt for food singly or in pairs on tidal mudflats or on the reef at low tide, poking their long bills into crevices for crustaceans and worms; they also have a curious habit of breaking open shellfish and hermit crabs by swinging them around (always clockwise viewed from behind) and dashing them open on a rock. Solitary birds are occasionally seen inland where they feed on insects and Scaevola berries, and also on the skinks of which the Plovers are so fond. On some Pacific islands Curlews have been observed stealing and eating freshly laid eggs of terns and other seabirds. For drinking seawater the bill was placed sideways in a pool, lifted out and held above the head for a few seconds, the operation being repeated several times. On the other hand Godwits lower the head and bill directly down horizontally into the water and lift up again with a slight scooping action. No doubt these two actions are governed by the characteristic shapes of the bills.

The haunting cry, something like "kiu-vee", carries far across the mudflats, and is frequently heard during flight. At high tide the birds are quiet and wary, and take shelter in small groups of six or so on a dry rocky or gravelly spit, often under the cover of shrubs, and never in the edge of the tide like some other species. They roost occasionally on the lowest branches of mangroves.

34. Limosa lapponica baueri. — Pacific Godwit. (Eastern Bar-tailed Godwit)

Kaka. (Kotau) — Kaka.

Slightly smaller in size than the Curlew, the Godwit is more greyish in plumage colour and may be easily distinguished by its long, almost straight (slightly upcurved) bill, which is longer in males. When birds arrive in the Colony about mid-October they are thin and pale-coloured in their winter plumage; after a few months' plentiful supply of food, however, they are plump birds by March or April when they leave again for the north; some males have by this time a handsome breast of reddish-brown for the breeding season.

The Godwit is seen chiefly on tidal mudflats, singly or in small groups; at high tide larger flocks of up to 50 birds may be found gathered on a dry spit or islet. Its food consists of tiny shellfish, other crustaceans and marine worms; it is amusing to watch a Godwit poke its bill down a hole in the mud and then run around its bill trying to locate the direction of the prey in the hole. On one occasion a Godwit passed along the ocean beach within five yards of where I was sitting; it was feeding on the small ghost-crabs which it dug out of their burrows in the sand, with the tide ebbing, and at intervals running down to the edge of the sea to wash its bill and have a short drink. On another similar occasion a Godwit was attended closely by two Turnstones which tripped in smartly under the

Godwit's head and stole the prey when opportunity offerred. By the end of November and until about the end of February they are comparatively uncommon, having presumably gone further south, and many local inhabitants have not realized their presence at all, although thousand must pass through the Colony on migration.

Godwits are fairly common in the Gilbert and Ellice groups but have not been reported from the Phoenix or Line Islands, although several observers have been in those places when Godwits would be seen if present. The writer visited the inhabited islands (Canton, Sydney, Hull and Gardner) of the Phoenix group in October, 1953, but did not record any Godwits. It seems likely, however, that a few stragglers may touch on the Phoenix group, but probably not the Line Islands which are 700 miles farther east. Stickney's map showing the probable eastern limits of the wintering range includes the Phoenix group without, however, any observational evidence. Baker records that the Godwit reaches Australasia by migrating to a great extent along the edge of the Asiatic continent, and that it probably reaches eastern Micronesia as an uncommon visitor, since it is occasionally recorded in the Hawaiian Islands. However, evidence assembled in 1954 by Stidolph indicates that the main migration route to and from New Zealand is further to the east than has hitherto been supposed ("well to the eastward of the Solomons"); my own observations in the Gilbert and Ellice Islands would add support to this view.

Their nests have been found in Eastern Siberia and Alaska; they are shallow depressions in the marshy ground, lined with reindeer moss and grass. Four mottled eggs are laid about June, and by August or earlier the young birds are ready to make the long journey south, some the nine thousand miles to New Zealand.

35. Erolia ruficollis ruficollis.	Red-necked Stint. (Eastern Little Stint)
Manu ote afa.	Nikunikun. (Raurau; Buatua)

This is the smallest wader recorded by the writer in the Colony, being only 6 inches or less in length and of correspondingly slight build. Its neck is very short and, during the quick darting feeding movements characteristic of the species, the head seems to be bobbing continuously in search of prey. Groups of up to 22 were observed on reefs or mudflats at low tide, often mingled with and partly concealed by larger groups of Turnstones. The rufous shades of the breeding plumages are often more noticeable than the greys of the winter dress.

One or two birds which were otherwise indistinguishable from the above at a distance but which had yellowish (instead of grey or black) legs may have been the Least Sandpiper, Erolia minuta.

36. <u>Erolia acuminata.</u> Sharp-tailed Sandpiper.
(Siberian Pectoral Sandpiper)

? ?

As with many other species of uncommon visitors, there appear to be no distinct vernacular names for this Sandpiper. Somewhat less common than the Stint, but not exactly rare (on Tarawa at least), this bird is fairly easy to approach within five yards or so. The slender body, rufous-brown crown, buff margins on brownish upperparts, greyish-fawn breast, white belly, dull olive-green legs and slender black bill were field characteristics easily distinguished through binoculars at this range. In flight whitish underwings with greyish edges and white axillaries were visible; there is also a pale inconspicuous upper wing-bar. On flying off the call was a quick "twee-twee-twee" or "chwee-chwee-chwee".

On several occasions groups of up to 34 in number were watched feeding on the soft red algal mud bordering brackish pools; another frequented habitat was the dry sparsely-grassed area of the school sports field at Bikenibeu, Tarawa, from which the birds appeared to be obtaining small insects. The Golden Plovers which considered this area their private territory often chased the Sandpipers off, even to the extent of pecking out a few feathers.

The only other record in the Colony is of 4 specimens collected by the Whitney Expedition at Canton on March 14th, 1924.

37. <u>Crocethia alba.</u> Sanderling.

The observed rarity of this attractive little wader in these islands is in agreement with Stickney's earlier report (1943) based on collections from the Whitney Expedition. Only two individual birds were observed by the present writer in three years. Both of these were at Tarawa, on November 8 and December 17. King observed one at Christmas Island on November 7; the Whitney Expedition included one male from Canton on March 12 and one female from Sydney Island on March 21.

One of the birds I observed was feeding on the reef at low tide among Turnstones while the other was alone on a sandy lagoon beach feeding at the edge of the tide and running busily back and forth with each wave; no calls were heard.

The Sanderling is slightly larger (about 8 inches) and more plump than the Stint. In winter plumage its very pale greyish upperparts, white face and white underparts, shortish black legs and black bill make it fairly easy to identify; it is the palest overall of the waders seen. A rather prominent broad pale median wing-stripe is visible in flight.

It appears that the Sanderling is an uncommon visitor over the whole Colony from October to March. Since its wintering range is world-wide it is puzzling that it is not seen in greater numbers.

III. CUCULIDAE (CUCKOOS)

38. <u>Urodynamis taitensis.</u> Long-tailed New Zealand Cuckoo.

Kaleva. Kabanei.
(Suvii)

About the time (August-September) when the first Arctic visitors are beginning to arrive the Cuckoo sets off on a long southern journey to spend the late spring and summer in New Zealand where it breeds. The earliest date of its return which the writer noted at Tarawa was March 20th. According to a Gilbertese legend this bird lays not on the ground or in trees but flies so high into the sky and the egg takes so long to fall that the youngster has hatched and is able to fly on reaching the ground again. A similar belief was held about the nesting of some other migratory birds such as the Curlew. The Marshallese have similar legends to account for reproduction among their bird migrants.

Another saying of the Gilbertese, especially in the southern islands of the drought belt, is that when the harsh cry of the cuckoo is heard in the bush, rain is not far off. In the Phoenix the bird is more rare and there is a belief that if the cuckoo's cry is heard above a house one of the occupants will be striken with severe stomach pains.

The Cuckoo is a bird of the forest and only brief glimpses of it are obtained during its straight and swift flight from one palm-top to another, or perhaps for longer periods during feeding. One of its favourite habitats is among the open flower-spikes of the coconut palm or near the sap-collecting gourds ("toddy-shells") around which there are plenty of flies, ants, and other insects which form its main diet. The bird is easily recognised by its hawk-like appearance, long tail, and by the characteristic harsh repeated whistle. This cry is heard at night as well as during the day but the exact location of the originator is often difficult to pinpoint.

According to Baker the northern limit of its migratory range is in the Carolines and Marshalls, being more common in the latter group. This distribution seems to be in agreement with observations for this Colony, where it is more common in the Ellice than in the Gilberts, rather uncommon in the plantation islands of the Phoenix (Sydney, Hull, Gardner), and appears to be unknown on the other (almost treeless) islands of the Phoenix, including Canton. There have been no authentic reports from the Line Islands; one Gilbertese native informant told me a few visited Christmas and Fanning. Its greater numbers in the Ellice, which lie within a heavier rain belt, may be partly due to the more dense bush there, affording more cover and probably greater food supplies. Its main winter range is eastern and central Polynesia, and Fiji.

IV ANATIDAE (DUCKS)

It appears that at least three species of migratory ducks from the New World visit islands as far south as the Ellice group quite regularly,

though not in large numbers at any one time. Unidentified ducks visiting Fanning (Kirby, 1925 and King, 1954) during the northern autumn were probably of one or more of these three species. Since the places they frequent on the atolls are usually rather secluded it is difficult to assess their numbers, distribution and seasons (if any). They are seen on freshwater ponds, brackish inland pools and on the stagnant water or in the vicinity of the sunken garden pits in which "babai" (Cyrtosperma chamissonis) is cultivated. Apparently they have not been hunted for food by the native peoples and, although they seem to be known on all islands, no distinction is given in vernacular names to the two species which I have seen. Since ducks are very adaptable in feeding and breeding habits there is the possibility of nesting occurring in the Colony. Sharpe and Whitmee (1878) obtained 3 eggs of a duck in the Ellice but no other details were given. Bailey quotes a man at Canton who reported seeing a nest with eggs of the Mallard in June, 1953.

39. Anas acuta tzitzihoa. Pintail.

? ?

Tristram reported a species of Pintail (Dafila modesta) from Sydney Island in 1886. This appears to be the same species as the present Anas acuta. King sighted one or two of these occasionally on ponds near the airfield at Christmas Island (1954), and a flock of 20 thought to be Pintails flying in off the ocean from the northeast on November 18.

It has not been reported from the Gilbert and Ellice groups, and was not sighted there by the present writer.

40. Anas platyrhynchos platyrhynchos. Mallard.

Toloa. Tiriwenei.

A female of this species was brought in to me from a babai pit at Tarawa on 16th October. It appeared to be rather weak and in poor condition but not injured in any way. Other single birds and pairs were seen at various islands in both the Gilbert and Ellice groups from September to December. From the few observations made and from the reports of other writers this seems to be the main arrival period, and April to June the departure time, although some may remain in this area the whole year round.

41. Spatula clypeata. Shoveller.

Toloa. Tiriwenei.

These ducks also seem to be regular but not common visitors to all islands. Two drakes in full colour were seen on 2nd April on freshwater ponds near the old airstrip at Bonriki, Tarawa. They were not easily approached but, after taking to the air several times, always returned to the same stretch of water. Ducks of this species have been observed at Canton and other islands of the Phoenix group.

APPENDIX A: PROTECTED BIRDS:

The following birds are protected under the Wild Birds Protection Ordinance of 13th October, 1921.

(i) Birds protected the whole year:
White Tern, Black-naped Tern, Crested Tern, Brown-winged Tern.
Brown Noddy, Black Noddy, Blue-grey Noddy.
Blue-faced Booby.
Greater Frigate-Bird.
Red-tailed Tropic-Bird, White-tailed Tropic-Bird.
Dusky Shearwater.
Reef Heron.

(ii) Birds protected part of the year:

Brown Booby:	December to April.
Turnstone:	September to February
Pacific Golden Plover:	September to February.
Bristle-thighed Curlew:	November to August.
Pacific Godwit:	September to February.

APPENDIX B: SOME COMMON TREES ASSOCIATED WITH BIRDS:

		Gilbertese:	Ellice:
Cocos nucifera	Coconut palm	Ni	Niu
Pandanus tectorius	Pandanus	Kaina	Fala
Scaevola sericea	Saltbush	Mao	Ngasu
Tournefortia argentea	Umbrella-tree	Ren	Tausunu
Cordia subcordata	___	Kanawa	Kanava
Pisonia grandis	___	Buka	Puka
Guettarda speciosa	___	Uri	Pua
Pemphis acidula	Ironwood	Ngea	Ngie
Calophyllum inophyllum	Tamanu-tree	Itai	Fetau
Artocarpus spp.	Breadfruit	Mai	Matalafi (?)
Rhizophora mucronata	Mangrove	Tongo	?
Morinda citrifolia	Malay Custard-apple	Non	Nonu
Ficus tinctoria	Fig	Bero	Felo

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ATOLL RESEARCH BULLETIN

75. *A Report on Typhoon Effects upon Jaluit Atoll*

edited by David I. Blumenstock

Issued by

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It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past fourteen years.

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Correspondence concerning the Atoll Research Bulletin should be addressed to the above

c/o Pacific Science Board
National Research Council
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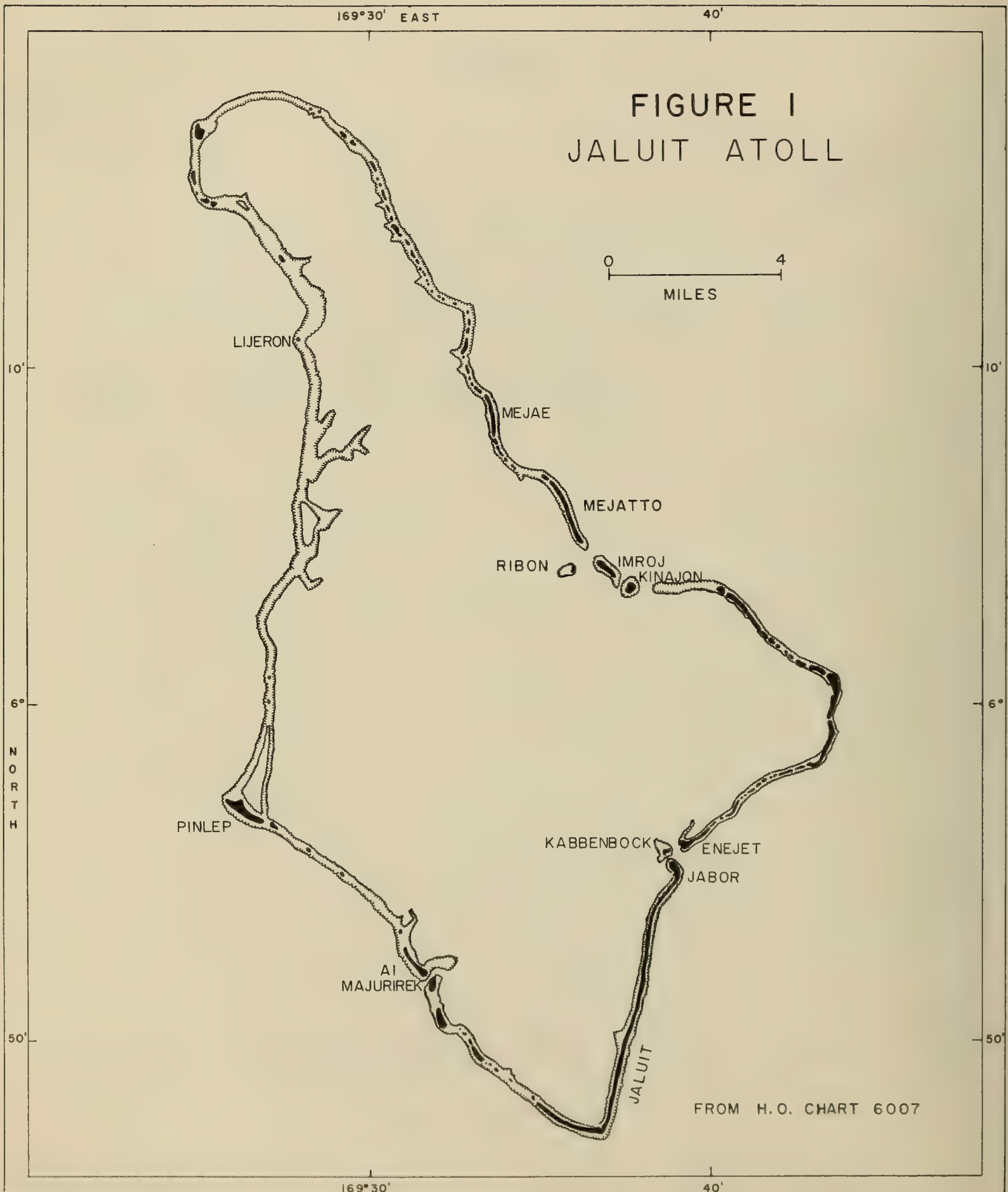

169°30' EAST
40'
FIGURE I
JALUIT ATOLL
0
4
MILES
LIJERON
10'
MEJAE
MEJATTO
RIBON
IMROJ
KINAJON
6°
NORTH
PINLEP
KABBENBOCK
ENEJET
JABOR
AI
MAJURIREK
50'
JALUIT
FROM H.O. CHART 6007
169°30'
40'

A report on typhoon effects upon Jaluit Atoll

I. INTRODUCTION

David I. Blumenstock

On January 7, 1958, a typhoon passed directly over Jaluit Atoll in the Marshall Islands (5°51' N., 169°38' E.). First reports indicated that the effects of the storm had been severe. The storm destroyed several villages and killed fourteen Marshallese (two more died of exhaustion shortly afterwards). The storm also radically altered the morphology of several islets, destroyed many hundreds of trees, and scoured out soils or buried them beneath a rubble mantle.

These reports of widespread damage and alterations were verified by my visit to the Atoll two weeks after the storm. Though my visit lasted but a few hours I was able to view all the islets from the air and to talk with Mr. J. B. Mackenzie, then resident agriculturist on Jaluit for the Trust Territory of the Pacific Islands. The storm effects had been unusually severe. Thus a unique opportunity existed to study in the field the kinds of effects produced upon an atoll that had been subjected to a direct hit from an intense typhoon.

Accordingly, the Pacific Science Board of the National Academy of Sciences--National Research Council, jointly with the Office of Naval Research and the Trust Territory of the Pacific Islands, sponsored the formation of a party of seven scientists to conduct a brief, but intensive, field study of Jaluit. The U. S. Navy provided air transportation to Kwajalein and facilities there, as well as airlift to Jaluit. In addition to myself, the field party included Dr. A. H. Banner, director of the Marine Biological Laboratory, University of Hawaii; Dr. F. R. Fosberg, Pacific Vegetation Project, U. S. Geological Survey; Dr. J. Linsley Gressitt, chairman, Entomology Department, Bishop Museum; Dr. Edwin D. McKee, geologist, U. S. Geological Survey; Dr. Herold J. Wiens, professor of geography, Yale University; and Mr. J. B. Mackenzie, of the Trust Territory. This group studied conditions on several islets of Jaluit during the period April 24 to May 2, 1958.

The members of the survey group are indebted not only to the organizations listed above but to the U. S. Naval Air Station, Kwajalein for providing logistic support and transportation to and from Jaluit, and to the staff of the District Administration, Marshall Islands District, Trust Territory of the Pacific Islands, especially District Administrator Maynard Neas and Milton Sideris, agriculturist, for local arrangements, transportation, and help in the field. The staff of the Bernice P. Bishop Museum, Honolulu, was especially helpful in organizing the expedition to Jaluit and in preparing two parts of this report. Dr. Yoshio Kondo of the Bishop Museum kindly identified the Mollusca collected by Dr. Gressitt; and Mr. E. H. Bryan, Jr., of the Museum contributed most of the information presented in Table I of the Introduction.

/Note:--Jaluit was revisited by a second party, under the same sponsorship, Oct. 20-29, 1960, to study recovery from the typhoon damage, and a report of this restudy is anticipated--Ed./

The findings of the field party are presented here, in the series of papers that comprise the principal sections of this report. Each paper was prepared by a single member of the field party, but views and information were exchanged freely among the party members and each benefited through discussions with the others.

As the editor of this entire report, I have taken the liberty of standardizing the usage of place names and of terminology. I have also inserted footnotes to refer the reader to relevant information in whatever paper it appears and to point up differences in interpretation among various members of the party. Footnotes for which I am responsible are followed by my initials (D.I.B.). Otherwise, except for occasional minor changes that it seemed to me would clarify the presentation, I have made no changes in the texts of the individual authors.

The reader may wish to refer to two papers already published on the Jaluit field study. One is my very general paper (Blumenstock 1958). This paper presents very briefly a few of the principal findings of the members of the field party. It is far less detailed than are the papers presented here and it adds nothing to them. It may, however, serve as a general introduction to these papers. The other is a paper by Edwin D. McKee (1959), which supplements and elaborates upon some of the results that he presents here. Those especially interested in the geologic effects of the storm should consult this paper.

Gross Geographic Features of Jaluit Atoll. Jaluit is a large atoll in the southern Marshall Islands. Its gross form is evident from the map of the atoll, Fig. 1. The features of chief interest are the large lagoon (approximately 15 X 30 miles), the presence of islets on all sides of the lagoon, the existence of three major passes (Southwest, Southeast, Northeast), and the presence of long, narrow islets on the eastern reef. Compared with other atolls, Jaluit is classed as having a deep lagoon. Most of the lagoon away from the reef is at least 15 fathoms deep and much of it is 20 fathoms or more. The greatest sounded depth within the lagoon is 29 fathoms.* There are a few scattered patches forming barely submerged or barely emergent reefs. Most of these are in the southern half of the lagoon. The maximum elevation is less than 20 feet above mean high tide and probably does not exceed 15 feet. Further, most of the islets lie below 12 feet above mean high tide.** Many of these general features are evident from Fig. 1.

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* U. S. Navy Hydrographic Office, Chart 6007, 1st Ed. May, 1944, revised 8/17/59. Soundings are available chiefly in the Pass areas and in the SE part of the Lagoon. It is likely that there are some depths in excess of 29 fathoms in the unsounded areas.

** Elevation estimates are based on the U. S. Army Map Service series (1:25,000), which do not, however, carry contours below 20 feet; and upon my general impression from having been on several of the islets and having viewed all of them from the air. Possibly the highest elevations above mean high tide are 12-15 feet on the northern side of Majurirek and the north to northwest side of Pinlep.

Jaluit is a rainy atoll, and had dense lush vegetation and well developed soils in many areas. The annual rainfall averages between 170 and 190 inches. The rainiest period is from May through November, when rainfall of 18 or more inches in a single month is common. During this period showers are frequent and the winds are often light and variable. The drier season extends from December through April. In the center of this period, from January through March, the tradewinds are especially strong and constant. Concurrently, monthly rainfall totals are often below 8 inches.

In a standard shelter at a 5 to $5\frac{1}{2}$ foot height, the temperature range at Jaluit is estimated as being from an absolute minimum of 68 or 69°F to an absolute maximum of 93 or 94°F. More commonly, the daily range is from the middle seventies to the high eighties. Temperatures tend to run 3 to 5° less during the dry tradewind season than during the rainy season. In the tradewind season maximum daily temperatures may be as low as 82 or 83°F and minimum temperatures, typically during nocturnal showers, may be as low as 70°F or even slightly lower.

Though moderate tropical storms pass near Jaluit every few years, the close passage of full-fledged typhoons is a rare event. Following the technical definition of a typhoon (or hurricane), which requires that it contain winds with sustained speeds of over 73 m.p.h. (63.4 knots), the passage of a typhoon center within a distance of 50 miles of any part of Jaluit Atoll probably does not occur more often than once in 20 years on the average. Further, these are typically small intense storms, with winds of typhoon speed extending outward no more than 25 or 30 miles from the center. The passage of a typhoon directly over Jaluit or within a very few miles of it is correspondingly an even more rare event. Such a very close passage probably occurs not more often than an average of once in 50 years.

The typhoon that hit Jaluit on January 7, 1958, was named OPHELIA. Prior thereto, in November 1957, two storms passed sufficiently close to Jaluit to produce some minor damage, chiefly on Jabor. These were the storms that later grew to typhoon intensity and became typhoons LOLA and MAMIE (Fleet Weather Central 1957). Thus the 1957-58 season appears to have been one that favored a high frequency of intense storms in the Marshall Islands, a fact associated with a major dislocation in the usual atmospheric circulation system throughout the entire tropical North Pacific (Blumenstock 1957). Prior to OPHELIA the last storm of typhoon intensity to pass very close to Jaluit was that of 1905 (Jeschke 1905-06). The older Marshallese on Jaluit recall this storm and state that its effects were much like those of OPHELIA

General History, Typhoon OPHELIA. OPHELIA was first detected as a disturbance near Palmyra (5° 23' N., 162° 5' W.), where it produced winds of 30 m.p.h. and heavy rainfall. It approached Jaluit from a general easterly direction, evidently moved directly across Jaluit, and then moved WNW through the Marshall and Caroline Islands and into the Philippine Sea, where it died out (Fleet Weather Central 1958). Among the other islands seriously affected by OPHELIA were Ponape, Truk, and the Hall Islands, all in the Carolines.

The typhoon intensity of OPHELIA was not known until it struck Jaluit and the word was relayed to Majuro by radio. Thus the storm appears to have deepened (intensified) rapidly between Palmyra and Jaluit.

Orthography. The names of the islets of Jaluit are spelled in many different ways. The spellings used in this report are shown in Table I, together with other spellings commonly used. Attention is called especially to the point that Jabor is used for the northern end of Jaluit Islet, as shown in Figure 1.

Organization of this report. The organization of this report is given in the Table of Contents. Attention is especially invited to the two Appendices, and to the Glossary, which defines certain terms used here about which there may be some difference of opinion. No concluding summary section is presented because it is felt that such can best be prepared after a re-survey of the Atoll to determine what the long-lasting effects of the typhoon have been.

TABLE I.

Place name spellings for some of the islets of Jaluit

Spellings used here[1]	Spellings on H. O. charts	Transliterated Japanese spellings
Ae	Ai	Ai
Enejet	Enybor	Eniboru
Imroj	Imrodj	Imuroji
Jabor[2]	Jabor	Jaboru
Jaluit[2]	Jaluit	Yaruto
Kinajon	Kinadyeng	Kinazen
Lijeron[3]	Lijeron	Rijieron
Majurirek	Elizabeth	Mejiruriku
Mejae	Medyai	Mejai
Mejatto	Medyado	Mejaddo
Pinlep	Pinglap	Pingurupu
Ribon	Ribon	

[1]Except where otherwise noted these follow the Marshallese and are based on the manuscript list compiled by E. H. Bryan, Jr.

[2]Used instead of Bryan's spellings because frequent, current usage makes it desirable to deviate here.

[3]This is Naen, according to Bryan's list; but according to J. B. Mackenzie and to local Marshallese informants, Naen is the adjacent islet and Lijeron is the correct name.

II. WIND, WAVE, AND STORM CONDITIONS AT JALUIT

JANUARY 7-8, 1958

David I. Blumenstock

The central physical events that led to the remarkable geomorphic, vegetative, and other changes on the islets and submerged reefs of Jaluit Atoll were the extreme wind and wave conditions that accompanied the storm. For this reason as well as from the viewpoint of intrinsic interest it is pertinent to reconstruct as accurately as possible the sequence of wind and wave conditions on January 7-8. In so doing, it is necessary to evolve a reconstruction that yields a coherent physical description of the storm itself: of its shape, size, intensity, and movement.

There are four major lines of evidence as to wind and wave conditions during the storm. These are the general (basic) tide conditions as given by standard tide tables, the accounts of natives, the vegetative evidence (especially direction of tree fall), and the geomorphic evidence. There are other, lesser, lines of evidence, as, for example, the destruction of a steel tower and the movement of a large storage tank. Each of these lines of evidence will be considered in turn, with a factual presentation of the observations together with my own comments as to their significance and accuracy. Thereafter I will present a summary of what I consider to be the significant, concordant evidence, at the same time making clear why certain evidence has been discarded or adjusted. Finally, I will estimate what the succession of wave and wind events were as related to the nature and movement of the storm that was the generating agent.

Basic tide conditions

Figure 2 shows the mean tidal height at Jaluit Atoll from 0500 to 2400, 180th meridian time, January 7, 1958.* The significant feature of this curve is the range of 6 feet, which is a very large range compared with the average, for this was a spring tide day. The upper portion of Fig. 2, which refers to wave conditions upon different islets, is discussed below.

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* Time and height of the two pairs of high and low tide points are taken from U. S. Coast and Geodetic Survey 1957. Intermediate (hourly) values have been obtained through applying the short form for interpolation given in this reference.

Accounts of natives

Accounts of the sequence of events during the storm were given to me by the Head Chief of Majurirek Village, by Mr. Katje, a Marshallese employee of the Trust Territory, and by Mr. Morris, the Head Chief of Imroj Village and the Head of the Chiefs' Council for the Atoll of Jaluit. The account by the chief of Majurirek Village, was given through an interpreter. In contrast, Katje and Morris gave their accounts in quite good English, though two or three times Morris switched to Marshallese, which was then translated by Katje. In each instance the informant was asked to describe in his own words what took place and in what order, especially with reference to wind, wave, rain, and falling trees. Only after he had completed his narrative was the speaker questioned regarding specific points. The accounts of each of these three are given below, with a distinction being made between information that was volunteered and that which was given in answer to questions, since there might be a tendency for any one of them to answer a question in such a manner as to attempt to please the person asking it. All the accounts have to do with conditions on January 7th or in the early morning on the 8th. The accounts are from my abbreviated notes and are not intended to give the exact words or an exact translation of the words of the speaker. All times are local (approximately 180th meridian).

Account of Head Chief of Majurirek Islet, with reference to conditions on Majurirek

Information volunteered: Around 8 in the morning the wind was from the north, not too strong. About 10 o'clock the wind started to blow "full", still from the north. Around 2 o'clock in the afternoon the wind went to northwest and at the same time there was a little wave that came in from the east and onto the islet (on the lagoon side). By late afternoon, around 4 o'clock, there were big waves from the east, and these went up the shore quite a way. Then for about four hours the wind was very full and it went from northwest to west to southwest and then to south. After this (about 10 p.m.) the wind died down.

Question: How far up the shore did the big wave come (from the lagoon in early afternoon)? Answer: About 10 to 15 feet up the shore. Question: When did the trees start falling down? Answer: From the time when the wind was full from the north through the time it was very full from the northwest and west. Question: Were there waves from the ocean? Answer: Yes, but only small ones. Question: Did it rain? Answer: Yes, there were heavy rains from around the middle afternoon until past midnight.

Account by Mr. Katje with reference to conditions on North end of Jaluit Islet (Jabor)

Information volunteered: At about 9 o'clock the first big wave came from the east, and it went over the southern part of Jabor (the narrow part). The wind then was from the north. The second big wave came across from the east around noon. Still the wind was from the north. About 3 p.m.

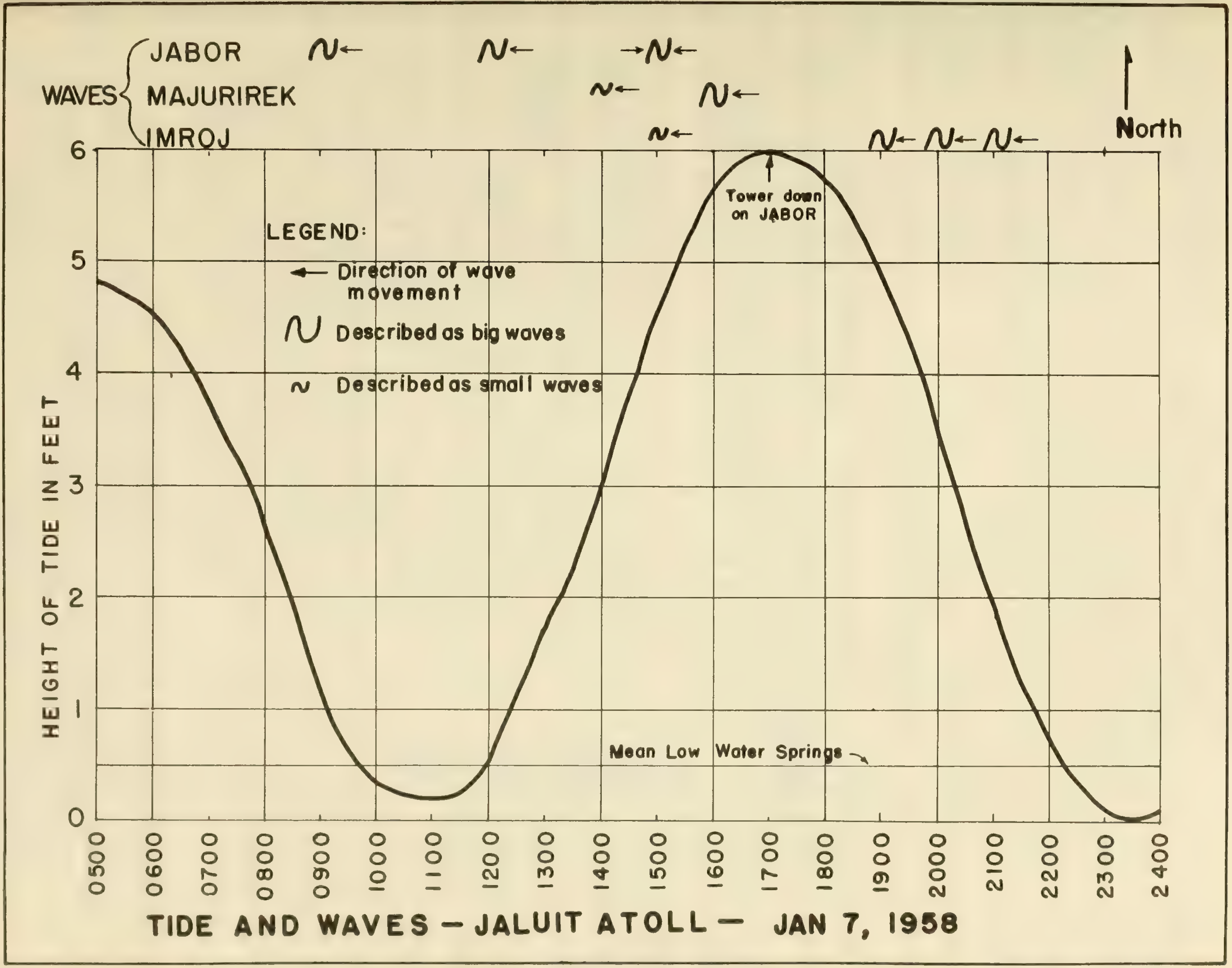
WAVES
JABOR
MAJURIREK
IMROJ
North
Tower down on JABOR
LEGEND:
Direction of wave movement
Described as big waves
Described as small waves
Mean Low Water Springs
HEIGHT OF TIDE IN FEET
0
1
2
3
4
5
6
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TIDE AND WAVES — JALUIT ATOLL — JAN 7, 1958

FIGURE 2

TABLE II.

SUMMARY OF EVIDENCE BY INFORMANTS

Approximate Time*	NAME	OF	ISLET		
	Majurirek		N. Jaluit		Imroj
0700					•
0800					•
0900			←∿		•
1000	+				•
1100	+				•
1200	+		←∿		•
1300	+				•
1400	←~ +				•
1500	+ ∴		→∿ ←∿		←~ •
1600	←∿ + ∴				•
1700	+ ∴		⊙		•
1800	+ ∴				•
1900	∴				∿← ∿← •
2000	∴				←~ •
2100	∴				⊙ •
2200	∴				•
2300	∴				•
2400	∴				
January 8.					Morning

*180th meridian time

NOTE: Light to moderate wind. Very strong or full wind. Strongest wind

Arrows fly with the wind. North considered to be at top of page.

E.g. =S. wind

~ Small waves. ∿ Large waves. ← Arrows above wave symbols show direction from which the wave came.

• Light rain. ∴ Heavy rain. + Trees falling or being snapped.

⊙ Calm or very light wind.

big waves came both from the east (ocean) and the west (lagoon) and they came together and made a big jumble of water. The wind was still from the north. Then after a while it was all finished.

Question: When were the winds the strongest? Answer: From noon on. Question: What happened to the wind direction from middle afternoon on, did it change? Answer: In later afternoon it went from north to northwest, then to west. At nighttime it was southwest. By the next morning it was east. Question: Did the wind stop blowing at all? Answer: Yes, it stopped for a little while just before nighttime.

Account by Mr. Morris
with reference to conditions on Imroj

Information volunteered: Rain began around 7 in the morning. Wind began around 9 in the morning. Full wind started blowing around noon. There were some waves from the east around 3 p.m. The first really big wave came around 7 p.m. The second big one about 20 minutes later. There were six big waves all together, all from the ocean. After the waves there was one more very strong wind at about 8 p.m. About 9 o'clock the wind died down.

Question: The big waves -- the six big waves -- from the ocean, about how much time was there between them? Answer: Always about 20 minutes between them. Question: The wind that began in the morning and then became full about noon, what direction was it from? Answer: North. Question: The last big strong wind, around 8 to 9 o'clock at night, what direction was it from? Answer: North. Question: What happened to the wind after it died down? Answer: There was no wind from about 9 to 9:30, then the wind started from the south and it blew from the south until very late. Question: About how late would you say? Answer: At least 11 o'clock; but by morning the wind was from the east. Question: Were there any waves from the lagoon? Answer: Just small waves. Question: When, would you say? Answer: After nighttime, after the big ocean waves. Question: Was there any rain during the storm? Answer: Yes, light rain all the time. Question: Could this have been ocean spray? Answer: Yes, or ocean spray. Question: Did anyone think a storm was coming before the waves came? Answer: Yes, the old men thought so. Question: I know you were on Imroj, not Mejatto, but could you tell whether water came across Mejatto? Answer: The water did not come across Mejatto.

In Table II, I have summarized the information provided by the three accounts given above. I have summarized it as given, even though I am aware that it is not necessarily to be taken literally. For example, the time references can scarcely be accurate even within a half hour, for these men were busy saving themselves and their families and even those that wore watches certainly did not bother to look at them at least while the storm was at its worst. Note, also, for example, the inconsistency in Morris' account: He says there were six waves at 20-minute intervals, all between 7 and 8 p.m. I will refer to Table II later on and will then attempt to justify correcting it to accord with other evidence.

Vegetational evidence

Some evidence as to the direction of first very strong winds is given by the direction of dominant treefall and breakage on the different islets. This information is summarized in schematic map form in Fig. 3. In this figure two directions are shown where treefall and breakage was commonly observed throughout a direction range of 30-60°. With the exception of two of the islets for which arrows are shown, there was good concordance of dominant direction of fall (within the range of the wind arrows). The exceptions were northernmost Jaluit (Jabor) where Fosberg observed treefall from all directions, even though falls from the east to northeast seemed most common (wind E to NE). Similarly, on Kinajon Fosberg reported a wide variety of directions, though again with some dominance (north to northwest winds). Fosberg and Wiens are agreed on the overwhelming dominance of north to south fall (north wind) on Lijeron and they and I are all agreed on the dominance of west to east fall (west wind) in central Jaluit Islet (beginning about 300 yards south of the southernmost Japanese block house at the southern edge of Jabor). As for the dominant direction on north central Mejatto (about 1000 yards from the northern tip), I made a methodical count of trees snapped off and, judging from the scars, found that 45 had snapped towards the southwest (NE wind), 2 toward the south (N wind), 2 toward the east (W wind), and one toward the northwest (SE wind).

From the uprooting and snapping off of trees, what conclusions can be reached regarding windspeeds? From discussions with Fosberg and judging from my own observations on Guam after that island was sideswiped by typhoon LOLA*, I believe the following estimates are warranted:

(1) On Mejatto, where palms and many other kinds of trees were snapped off, sustained windspeeds certainly exceeded 125 knots (from NE among other possible directions);

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* LOLA passed south of Guam in November, 1957. Two or three weeks later I stopped on Guam and spent seven days in the field studying what the effects of the storm had been upon the land and upon the vegetation. Recorded windspeeds on Guam reached a maximum of 83 knots sustained speed and 103 knots for the peak gust, both on top of Mt. Alutom. Speeds in less exposed locations, as along the southern and eastern coasts, were around 50 to 70 knots sustained (over 60 at the Naval Air Station). It is reasonable to suppose that very locally, because of funneling effects and the like, speeds elsewhere reached 70 to 80 knots, sustained. Where breadfruit or pandanus stood in exposed locations, they were often down or snapped off a few feet below the crown. Yet I saw no palms either snapped off or down except in the coastal region from Inarajan to Merizo -- a region that had been inundated. Casuarina, like the palms, also stood well against the wind. Thus on the open beaches on the east coast of Guam, a few miles south of Ylig Bay, there were open stands of Casuarina, that had been well exposed to the winds, and among these many hundred trees I found only one that was down, and it stood east (oceanward) of the strand line where washing out of roots must have occurred just as it was observed to have occurred among neighboring trees that were still standing.

Figure 3

Dominant Directions of Tree Fall or Snapping

Directions are shown by wind arrows with reference to winds that would produce observed fall (assuming trees fall toward downwind direction). Wind arrows fly with the wind. Directions shown to eight points only. Where two arrows are shown dominant fall was from two directions as shown.

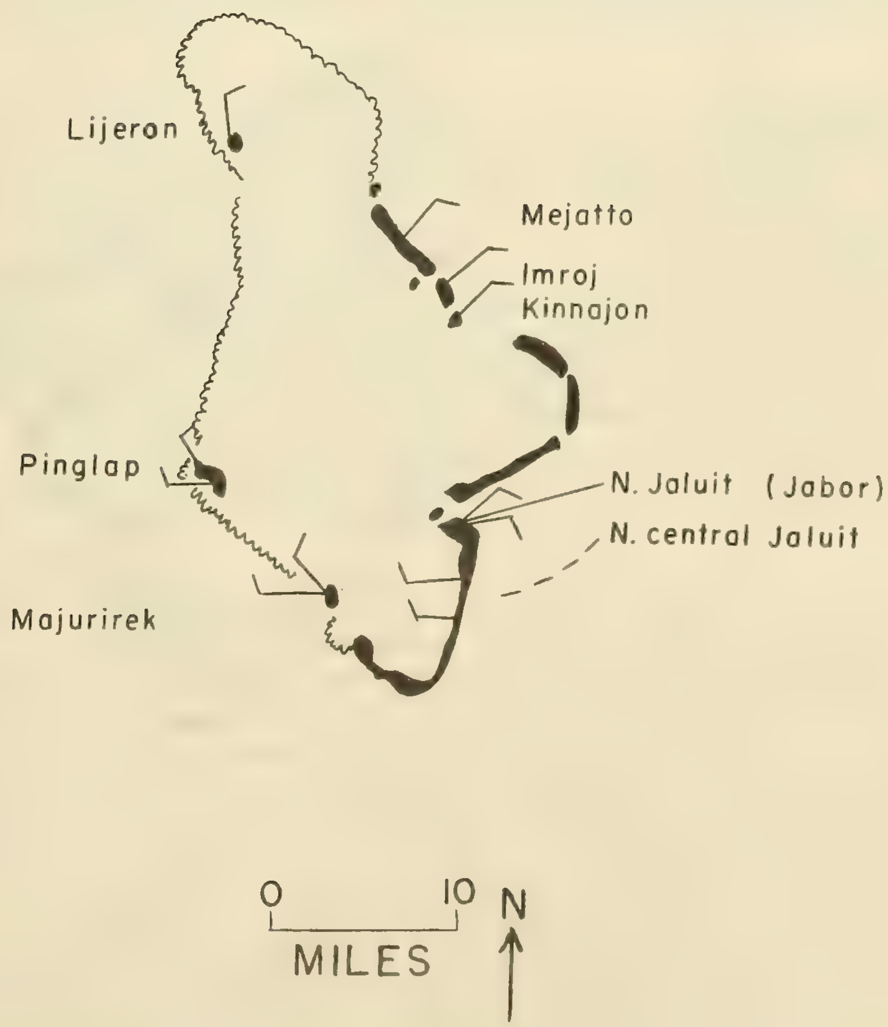


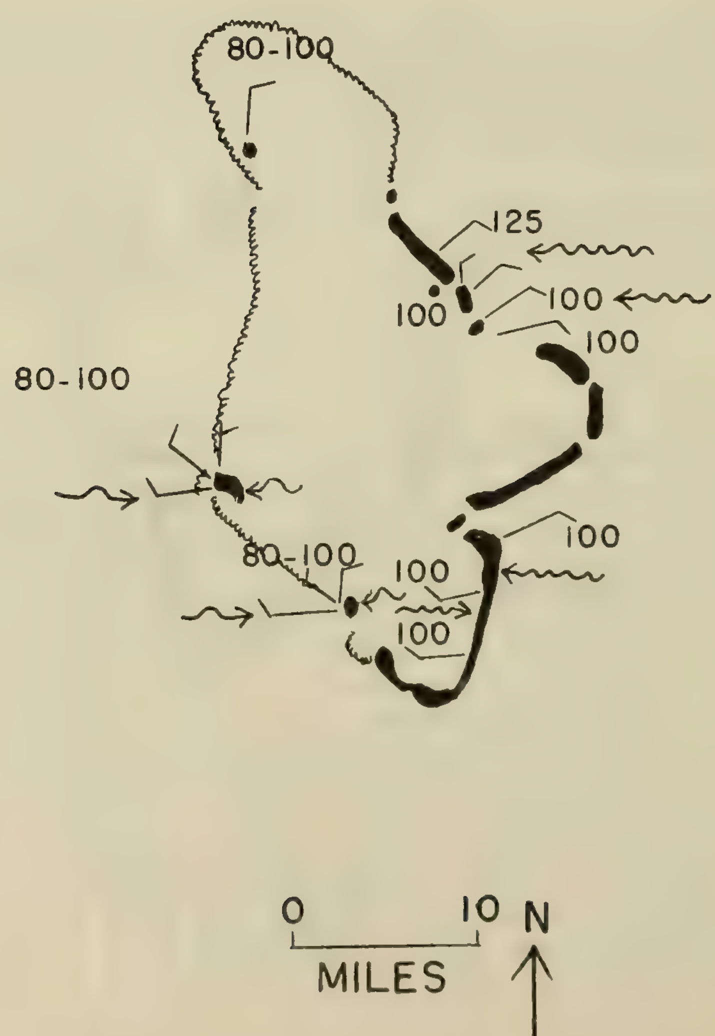
Figure 4

Minimum Speeds of First Strong Winds and Dominant Directions

Of Water Movement Across

Islets

(Deduced from vegetative and geomorphic evidence. Wind directions are to 8 points; windspeeds, in knots. Wind arrows fly with wind. Wavy arrows show direction of dominant water movement, with longer arrows representing major inundations and shorter arrows representing lesser inundations.)



(2) On Imroj and Kinajon the maximum windspeeds were perhaps slightly less (certainly, however, in excess of 100 knots). Here, as on the islets of Majurirek, Pinlep, and Lijeron, allowance must be made for the extent of tree stands -- the massing of trees on relatively wide islets. The same massing occurred at the northern and southern tips of Mejatto, where relatively few trees were snapped off or blown down compared to the 90% or more that were snapped or down throughout the central 2-2½ miles of Mejatto.

(3) The vegetative evidence shows that windspeeds on Jaluit Islet were also in excess of 100 knots (snapping from west to east south of Jabor, direction confused but generally east to west in northern Jabor). However, as Fosberg noted, beyond South Point there were far fewer trees snapped or uprooted than to the north of South Point.

(4) The evidence on Majurirek and Pinlep shows maximum sustained winds (from between north and west at time of fall or snapping) of at least 80 knots and probably at least 100.

(5) On Lijeron the maximum sustained winds were from the north at speeds comparable to those on Majurirek and Pinlep.

In general, no estimate of windspeed is warranted where trees were blown over during inundation. The above estimates are made on the basis of trees observed to be blown down where no inundation occurred or on the basis of trees snapped off.

Vegetational evidence also provides clues as to the dominant direction of water movement across various islets. On the lagoon side of Mejatto at several different points, some palms and other trees had been washed westward (or southwestward) and at the time of the survey were standing in water several fathoms deep. Clearly marked strand lines indicated inundation from east to west (or northeast to southwest) across the ocean beaches and almost to the center of Imroj. These same inundation directions held on Majurirek and Pinlep, but with the strand lines at lower levels, 4-7 feet above mean high tide (the spring tide would account for about 1 foot of this amount). On the other hand, strand lines indicated much lesser inundations from the ocean eastward (southeastward) onto Majurirek and Pinlep.

Finally, there was another curious line of evidence that is not conclusive but is suggestive. On central Mejatto, as Fosberg pointed out, the palm roots exposed by the erosion accompanying the inundation were, with two exceptions, combed in an east to west direction. This would appear to indicate that the water drained from east to west off this part of the islet. In contrast, in the gentle topographic trough just back (west) of the steep ocean beach on Mejatto, there were two roots (the only ones visible) that were combed south-to-north. This same trough contained large quantities of vegetable strand material, yet there was no source for such material on the beach to eastward. Two roots and some strand debris are not much evidence on which to hang an hypothesis, but I am inclined to guess that while the main body of water drained from east to west, some remained in the topographic trough and that thereafter this water was blown northward by a strong south wind, thus accounting for the perverse

combing of the roots. As for the strand material, it may well have been brought in from the ocean during periods of strong tradewinds after the storm, having been derived initially during the storm not from Mejatto at all but from islets to the southeast -- to the east and south of Northeast Pass.

My interpretations of the vegetational evidence, discussed above, are summarized in schematic map form in Fig. 4.

Geomorphic evidence

On the several islets that were visited by the members of the field party, there is ample and usually quite consistent geomorphic evidence as to the direction of movement of water onto or across the land. To what extent the water came upon or across the land simply as huge, wind-driven waves and to what extent as a true surge -- a term that requires a local rise in sea level due to the friction of wind upon the water -- is another matter, and one on which the geomorphic evidence is not conclusive. Almost certainly both these factors were involved, at least on such eastern islets as Jaluit and Mejatto, which were under water to depths of at least one or two feet, as the following discussion makes clear.

The geomorphic evidence consists of depositional and erosional forms of the following kinds:

Depositional

Subaerial at least at low tide

1. Bars and ridges, emergent at least at low tide
    a. Upon reef flat, but separated from the land at mid-tide.
    b. Upon the reef flat, but tied to the land at mid-tide.
    c. New or augmented beach ridges upon the islets above high tide.
2. Patches or sheets of rubble
    a. Upon the reef flat, below water at mid- to high tide.
    b. Upon islets and emergent at high tide.
3. Irregular debris mounds upon islets, above high tide.
4. Pronounced strand lines upon islets, above high tide.

Submarine

1. Sediments, chiefly fine, deposited on floor of lagoon to west of several of the eastern islets.

2. Submerged portions of bar and ridge forms in lagoon to west of northern Jaluit Islet.

Erosional

Subaerial at least at low tide

1. Scour channels cut across islets (or for distances of many tens of yards across much of islet)

2. Scour pits and plunge holes, upon islets, roughly round to oval and without such channel features as marked elongation with undercutting for distances of at least tens of yards along sides to form distinct lateral boundaries

3. Breaks in older boulder ridges or in ridged beach rock

4. Beach scarp, cut in unconsolidated materials

5. Evidence of removal of fines in irregularly-shaped areas upon islets

Submarine

No evidence was seen directly of marked erosion below low water height, although at least one scour channel on Mejatto extended as a submarine feature for a distance of a few tens of yards into the lagoon. Presumably there was erosion of the reef front on the ocean side of the eastern islets, with rock fragments being torn from the reef or plucked from crevices on the reef front where they may have lodged after breaking off some time prior to the storm. However, the reef front on the ocean side was not examined.

These geomorphic features are described in future chapters. Here all that will be done is to mention these features, islet by islet, as they constitute evidence of water movement.

MEJATTO: Evidence: Gravel sheets thickest and most extensive on eastern (ocean) side of islet, thinning out and usually disappearing on western (lagoon) side; pot holes and scour pits excavated east to west as evidenced, for example, by their lying to the west of such obstructions as massive tree roots; fine sediments deposited chiefly along western side of islet and onto adjacent reef-flat and submarine slopes on lagoon side; most prominent scour channels begin on eastern side at break in old boulder ridge and extend westward. (Non-geomorphic evidence: Dead trees in lagoon with tendency to cluster near western end of scour channels.)

Conclusion: Dominant water movement was from east to west (ocean to lagoon) and water moved entirely across the islet except in the extreme north and south.

IMROJ: Evidence: Of the same kind as for Mejatto, but without the striking fine-sediment features on the west side and except that islet was not completely inundated.

Conclusion: Dominant water movement east to west.

NORTHERNMOST JALUIT

Evidence: Gravel ridge upon reef flat, ocean side, comprised largely of corals typical of reef front*; gravel sheet thinning out from east to west (toward lagoon); boulder about 4 X 4 X 6 feet lying 15 yards to west of ridged beach rock from which it was torn (and into which it could have been fitted); fine sediment deposits on western (lagoon) side; rubble from paved road carried east to west, into lagoon.

Conclusion: Dominant water movement east to west.

CENTRAL JALUIT (southern Jabor and southward extending a distance of about 1 mile south of old Sydneytown at the water tank).

Evidence: Gravel ridge upon reef flat on ocean side lower than farther north (0.5-4 yards high as contrasted with 3-8 yards farther north, except for one mound-like feature which was about 6 yards high, about 30 yards in diameter) and giving way to rubble patches in some places. Emergent ridge in lagoon, evidently composed of a high percentage of fine sediments as judged by view from shore; this ridge paralleled the shore at a distance of about 200 yards, and was barely emergent at high tide. Piece of glass found among debris that formed ridge on reef flat on ocean side. Rubble sheet more patchy than farther north and consists of only scattered coral-rock fragments in series of shallow channels that extend from near the ocean side (a few yards or tens of yards away) westward into the lagoon. Large water tank displaced from west to east a distance of about 200 yards (see p. 21).

Conclusion: Dominant water movement from west to east across islet.

PINLEP: Evidence: Small wave-cut scarp on western side of islet. Remnants of pronounced strand-line at about 5 feet above mean sea level on northern and eastern sides.

Conclusion: Dominant water movement probably alternately from east and from west.

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* See Banner's description, p. 76.

MAJURIREK: Evidence: Pronounced but small scarp, 3-4 feet above mean sea level, seemingly wave-cut, on western and southwestern side of islet. This scarp under-cuts some palms.

Conclusion: Dominant water movement, west to east. If there was water movement from east to west it was probably slight.

The conclusions stated above concerning dominant water movement onto or across the various islets are summarized in schematic map form in Fig. 4.

Other evidence regarding wind, wave, and storm conditions

Miscellaneous evidence is as follows:

(1) Mejatto-- All houses and other buildings were demolished, leaving not a trace that I could find. These were chiefly thatched native huts, though some were made from pieces of wood or lumber.

(2) Imroj-- Thatched huts were destroyed. Those made of boards were at least severely damaged, while some were totally demolished and others were partially demolished (roofs off, walls blown or washed in, etc.).*

(3) Central to northern Jabor-- Radio tower (steel tower) went down about 5:10 p.m., when radio went off the air (J. B. Mackenzie states this time is correct within a few minutes; he was on Majuro, where the broadcast was being received). All buildings demolished except for Japanese-built blockhouses, which were sunk 5-8 feet in the coral rock. Most buildings were completely swept away, leaving no trace, including the plywood buildings constructed only 12-18 months before by Holmes & Narver, American contractors. Some metal and wood remnants of buildings were found strewn about in an area to the east of the blockhouse building that was used as the headquarters for the Trust Territory government officials. One of the two water tanks was moved about 200 yards eastward from its concrete platform. An almost perfectly straight trench was scoured out to a depth of 3-4 feet, and this appears from old aerial photographs to have been a narrow water trench in Japanese times. (The trench runs almost due east from the lagoon to the ocean.) Scouring to a depth of 6-8 feet occurred at the NW corner of the southernmost blockhouse, leaving an irregularly shaped pit about 12 yards in diameter.

(4) Pinlep and Majurirek-- We were told that virtually all buildings had been blown down: that thatched huts were flattened by wind and that wooden shacks "flew apart". We observed some wood debris here and there but all buildings that I saw had been put together again, so this was not a direct observation.

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* For a different estimate of degree of damage, see Wiens, p. 29.

(5) Path of storm-- According to J. B. Mackenzie, who surveyed the damage at Mili Atoll, OPHELIA caused the most wave and water damage on the north side of that atoll. Mili is at 6°10'N, 171°55'E. According to Fleet Weather Central (1958) OPHELIA was heading WNW when located to the west and slightly north of Jaluit, after passing over Jaluit.

Reconstruction of events as related to field evidence

It is impossible for me even to imagine a series of storm events that would follow in logical order according to what is known about typhoon structure and movement and that would satisfy all the evidence cited above. Virtually all the evidence would be satisfied by supposing that a small, intense typhoon with multiple centers passed over Jaluit on January 7-8, but this relatively easy solution of the problem does not seem warranted since I have found no known instance of multiple eyes in a typhoon a mere 50 to 70 miles across, which must have been the diameter (diameter of winds over 63 knots) of this one to satisfy even the preponderance of the evidence. What is most common is an eye, evidently often irregular in shape, and which changes its size and shape almost constantly. My reconstruction follows, placed side-by-side with the evidence both pro and con. The reconstruction is represented by the series of schematic maps in Fig. 5.

RECONSTRUCTION

1. On January 7, 1958 at 9 a.m. (180th meridian time) a small intense typhoon was approaching Jaluit, moving in a direction from 80° towards 260° at a speed of 5 to 7 knots. The storm was following a sinuous path and was later to curve first due westward, then west-northwestward as it crossed Jaluit. At the time the circulation about the storm was well defined with winds of 50 knots or more extending outward to a distance of 25-30 miles in the southwest quadrant, 30-40 miles in the NE quadrant, and 40-50 miles in the northwest quadrant. The northwest quadrant held the strongest winds, which were over 100 knots near the storm center, and the winds in this quadrant and around slightly into the west were strengthened well in advance of the storm by greatly intensified tradewinds that under the influence of the storm circulation had previously backed (shifted

EVIDENCE AND REMARKS

1. a. Supporting evidence: Winds were northerly at North Jaluit and Imroj at this time (Table II). There was light rain at Imroj, which is consistent, and that Katje failed to report rain at N. Jaluit is immaterial since he failed to report rain at any time -- and no rain at any time is a virtual impossibility. Katje stated large waves from the east were pounding the Jaluit reef. I accept this and point out that it was almost low-low tide so that this would help loosen debris along the reef front. Quite likely some of this coral debris was being already thrown up on the reef to form the debris bar that later was so evident on the ocean side of N. Jaluit. There is no evidence that winds were yet strong enough to topple trees or snap them. The winds were still probably moderate as reported by Morris and Katje, and I accept this as partial evidence, consistent with later evidence, that the center of the storm was still far distant, about 45 nautical miles away. The estimated speed of 5-7 knots brings the storm center in at about 4-5 p.m., and this later

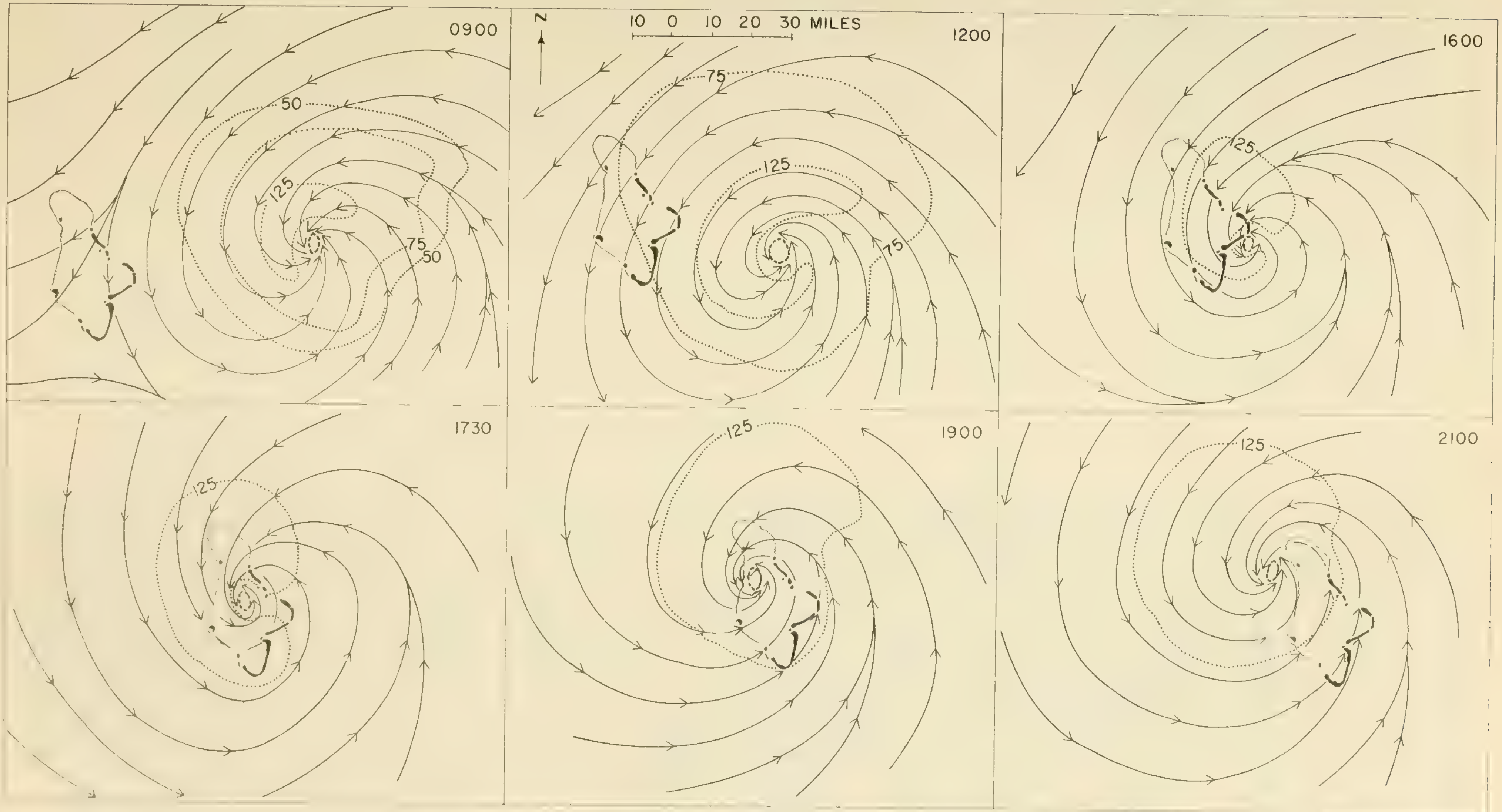


FIGURE 5 Schematic Streamline Charts Typhoon OPHELIA

JALUIT AREA JAN. 7, 1958 — Legend: Windflow Isotach (knots) Center winds <10 knots

RECONSTRUCTION (CTD.)

counterclockwise) to around 10-20°. The storm center was ill-defined, but generally elongated and was oriented with the major axis normal to the direction of storm movement. The storm center was about 7 hours -- roughly 45 nautical miles -- away from the eastern islets of Jaluit. As the storm approached it was itensifying (see Fig. 5).

EVIDENCE AND REMARKS (CTD.)

seems borne out (discussed below). The approach of the storm from about 80° is supported by the fact that it had passed north of Mili Atoll.

b. Negative evidence: Morris failed to comment on strong waves until about 3 p.m.). I discount his statement (a matter of what one calls strong waves) and point out further that it was raining (affecting visibility) and that waves coming dominantly from somewhat to the north of east may have piled more heavily onto North Jaluit than onto Imroj due to piling of water along ocean side of islets to the NE and "guiding" of waves of unusual size onto North Jaluit. Note also that Katje was on a very narrow islet as compared with Morris, so that Katje could readily see heavy surf with some waves topping onto land whereas Morris could not. The Majurirek chief reported strong north winds only an hour later (10 a.m.) with some trees down, but I must discount this and believe that the winds were merely fresh NNE with a few branches falling and that the extreme winds did not arrive on Majurirek until several hours later (between 3 and 4 p.m., when the chief began to report extremely high winds with heavy rain).

c. Remarks: For elongate centers perpendicular to storm path, note that this was characteristic of hurricane DOT in the vicinity of Kauai, Hawaii, in 1959 (as shown by aircraft reports and radar plots on file, mss. U. S. Weather Bureau, Honolulu); and for speed of movement, while 5-7 knots is somewhat slow it is certainly not unknown in this area (see data for LOLA, Fleet Weather Central 1957). As for small size and irregular shape of these storms (with ill-defined centers), as well as for their suddenness of appearance, see *e.g.*, the information on the Hong Kong Typhoon of 1906 (Gibbs 1908).

RECONSTRUCTION (CTD.)

2. January 7. 12 (noon). The storm center was now about 30 nautical miles east of Southeast Pass and the storm was now approaching from about 100° (moving towards 280°) along the path shown in Fig. 5 and with winds as also shown in that figure. Waves were very strong from the east and against the reef on the ocean side of the islets from Northern Jaluit northward. It was just past low-low tide and debris had now been heaped high upon the ocean reef front in Northern Jaluit. There were N to NE winds at speeds in excess of 80 knots from Northern Jaluit northward (on eastern islets) and there was some toppling of trees that were poorly rooted or were awash near the eastern edges of the islets. There was snapping of branches on a wide scale, but no snapping of trunks of any but the very weakest trees. At Majurirek and Pinlep the winds were very fresh and northerly. With the ill-defined center, elongated now N-S, the windspeeds slacked off rapidly from N. Jaluit southward (Fig. 5). Occasional waves threw water across northernmost Jaluit, from east to west, but on Imroj (which is a higher islet) the waves only moved well up onto the eastern side. Nor had waves begun to sweep across Mejatto as yet, although there was heavy pounding of the boulder ridge along the eastern side of that islet. No waves of any magnitude were yet upon the western islets, though the very fresh northerly winds were piling some water into the southern part of the lagoon and producing some water up the beaches with superimposed small waves generated in the limited fetch area within

EVIDENCE AND REMARKS (CTD.)

2. a. Supporting evidence: The wind situation generally fits that given by the three informants, although winds were not directly from the north as reported. The wave (water) across North Jaluit was as reported by Katje. Dominant tree-fall and tree breakage directions support the view that not many trees were down or were snapped this early in the sequence. Before this happened the storm must tighten, change direction slightly, and come in so as to provide very high windspeeds from the northeast quadrant from N. Jaluit northward on the eastern islets.

b. Negative evidence: The Chief on Majurirek said trees were falling at this time. I believe he must have been off on his time or else that he was referring only to a very few trees (poorly rooted) going down or to breakage of branches, which would require only a wind of 50 knots or so. In this I am consistent in that field evidence shows the preponderance of trees going down before a wind from NW to W (falling SE to E) rather than from N or NE (Fig. 3).

c. Remarks: The elongate center with windspeeds decreasing very abruptly within a distance of a few hundred yards on N. Jaluit is necessary to account for the amazingly sharp transition from trees down from the NE to E (northernmost Jaluit) and from west to east (just south of northernmost Jaluit). This point is elaborated upon in the sequence that follows and in the corresponding evidence and remarks.

RECONSTRUCTION (CTD.)

the lagoon. Water was also running in through the eastern passes and the lagoon was perhaps 1-2 feet above normal level in the southern end; but still it was just above low-low tide so this did not represent an abnormal condition with reference to mean sea level.

3. January 7. 4 p.m. The storm center had become smaller and better defined and was now a few miles to the east of northernmost Jaluit (see Fig. 5 for location and for winds). The tide had been rising and was almost high-high. Water was crossing central and northern Jaluit from east to west, and was also crossing all but the extreme ends of Mejatto. Maximum winds were being or had been experienced during the past few hours from northernmost Jaluit northward (on eastern islets). Speeds exceeded 100 knots and trees were toppled. With extreme gust speeds exceeding 150 knots trees were snapped in this area, but there was a very sharp wind gradient and north central Jaluit had not yet received winds of these speeds. On Majurirek and Pinlep winds were from N to NW at speeds of close to 100 knots and trees began to fall where they were poorly rooted and much exposed (not shielded by massing) as along the upper beach on the north to northwest sides of these islets. The storm was now moving from about 70° and towards 250°.

4. January 7. 5 p.m. The chief significance of this time is that now the storm center had just passed into the lagoon and now also it was high-high tide. Within the past hour the waves crossing Mejatto and Jaluit had entered the lagoon and set up further waves that in combination with the basic tidal condition had

EVIDENCE AND REMARKS (CTD.)

3. a. Supporting evidence: Tree fall evidence fits this reconstruction with a single exception of E to W orientation of many of the fallen trees in northernmost Jaluit (see below). The general sequence of events as described by informants bears out the reconstruction here, but I have had to move up Morris' statements re Imroj (that is make them earlier by 3-5 hours than what he stated) and have had to move back (make later by 2 hours) the statements of the Majurirek chief.

b. Negative evidence: Some of this is covered immediately above, where a time adjustment is explained. The other principal negative item is that the sequence as given in this reconstruction does not explain the east-to-west orientation of many of the fallen trees on northernmost Jaluit (Jabor). Some may have been swung around by water moving W-E; but the broad northernmost part was not thoroughly inundated. A temporary second eye centered over northern Jaluit Islet would take care of things, but since I am rightly or wrongly eschewing multiple centers I did not draw my map to cover this (Fig.5).

4. a. Supporting evidence: The time adjustments referred to above still apply; otherwise the evidence from informants as well as the vegetational and geomorphic evidence support this phase of the reconstruction of storm events.

RECONSTRUCTION (CTD.)	EVIDENCE AND REMARKS (CTD.)
caused flooding up-beach upon Majurirek, Pinlep, and other western islets. Trees fringing the beach had had their roots washed out and many had blown down before winds that were now backing to west at over 100 knots. By 5:30 p.m. or shortly after there were very strong NW to W winds across the southern part of the lagoon and this produced waves that now moved west to east from the lagoon onto Jaluit Islet. By 5:30 the strongest winds were past on the eastern islets north of northernmost Jaluit, but these strong westerly winds began to affect central Jaluit which was already wetted down; and between the flow of water (west to east) and the west winds, tree breakage and tree toppling now set in here. The radio tower had already gone down in northernmost Jaluit and about now (5:30) the water tank was floated eastward from its former location.	
5. January 7. 7 p.m. (See Fig. 5). The storm was still intensifying and had accelerated slightly, to perhaps 5 knots. Furthermore, it had grown somewhat in size and the center was now better defined. It was centered over the northwest part of the lagoon. Winds were westerly on Majurirek and Pinlep, with speeds over 100 knots. Winds were southerly on the eastern islets, with speeds around 80-100 knots. The water had largely drained from Mejatto and from the very highest parts of Jaluit. It was raining very hard on the western islets, but there was only moderate rain on the eastern islets. Winds were now maximum and northerly on Lijeron, and trees were going down there. Some were snapping.	5. a. Supporting evidence: With time adjustment already noted, this fits the evidence.

6. January 7. 8 p.m. About now the storm center cleared Jaluit Atoll, moving slightly north of west with the center passing a few miles to the south of Lijeron. This was an elongate center, oriented N-S (Fig. 5). Winds continued strong southerly over the northeast islets, were out of the SW and strong on the southeast islets, were very strong and out of the SW on the southwest islets, and were going to very strong northerly at Lijeron.

6. a. Supporting evidence: The evidence is all supporting (informants, vegetation, geomorphic) except that again a time adjustment is needed for Morris' account re Imroj. The south wind over Mejatto helps explain the orientation of combed roots, as suggested above (pp. 9-10). The Lijeron and Pinlep tree-fall evidence supports the view that the center must have moved westward out to sea between these islets, with a very elongate center to account for the lack of many east-west treefalls on Lijeron. Note that Lijeron and Pinlep were largely not under water, so water could not swing many fallen trees around here as it might have done on Jaluit or Mejatto.

7. January 7. 9-10 p.m. As the storm continued WNW away from the atoll the west to east wave within the lagoon carried some water against and slightly onto such northeast islets as Imroj and Mejatto.

8. January 7. 11 p.m.-midnight. Winds had slackened and now were generally southerly to southwesterly across the atoll. Unusual wave activity had ceased save for swells that arrived on the western islets from the WNW and that appeared as unusual surf on the west to northwest sides of Majurirek, Pinlep, and other western islets but that had little geomorphic effect because it was now at or very close to low-low tide.

9. January 8. Midnight-7 a.m. Winds lightened continuously during this period and winds continued to back with fresh trades reestablished by morning. These trades washed ashore onto Mejatto and other islets vegetable debris that was carried out to sea on the eastern side of the atoll, chiefly material blown northeast to north from more southerly islets such as Kinajon.

7-9. Remarks: These sequences are consistent with the evidence as shown in Table II, in Figures 2, 3, and 4, and in the text on geomorphic evidence (pp. 10-13). The sequences also fit the fact that the storm was located to the west and slightly to the north of Jaluit on January 8 (see Fleet Weather Central 1958).

RECONSTRUCTION (CTD.)

The near high-high tide during this period promoted this wash-in of debris and helped form the pronounced debris line later observed. There was also some wash-up of debris onto the west to northwest side of the western islets during this same period because of the arrival of swell from the storm whose center was now (7 a.m.) 55-60 nautical miles away to the WNW.

EVIDENCE AND REMARKS (CTD.)

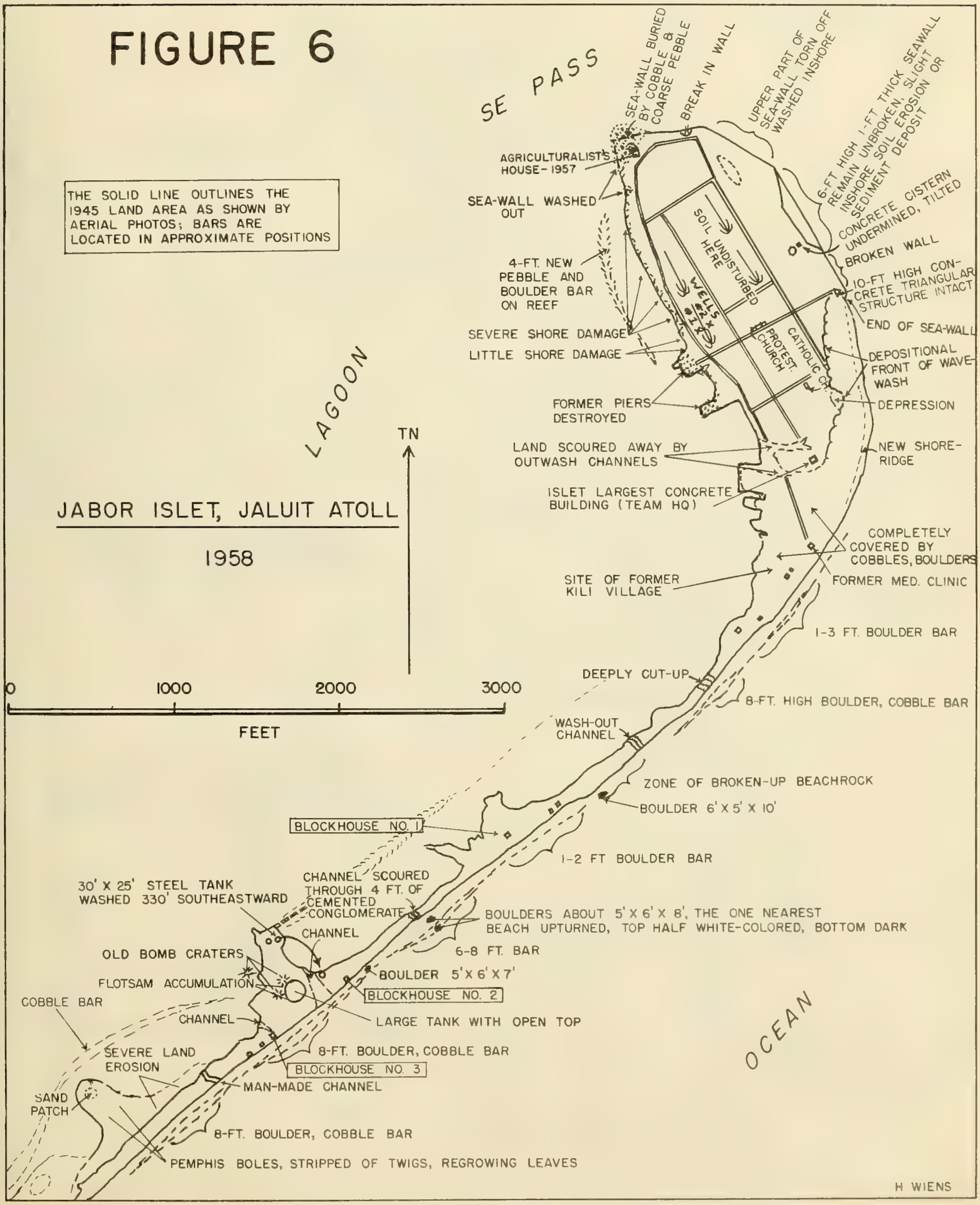


FIGURE 6
THE SOLID LINE OUTLINES THE 1945 LAND AREA AS SHOWN BY AERIAL PHOTOS; BARS ARE LOCATED IN APPROXIMATE POSITIONS
SE PASS
SEA-WALL BURIED BY COBBLE & COARSE PEBBLE
BREAK IN WALL
UPPER PART OF SEA-WALL TORN OFF WASHED INSHORE
6-FT HIGH 1-FT THICK SEAWALL REMAIN UNBROKEN, SLIGHT INSHORE SOIL EROSION OR SEDIMENT DEPOSIT
CONCRETE CISTERN UNDERMINED, TILTED
BROKEN WALL
10-FT HIGH CONCRETE TRIANGULAR STRUCTURE INTACT
END OF SEA-WALL
DEPOSITIONAL FRONT OF WAVE-WASH
DEPRESSION
NEW SHORE-RIDGE
COMPLETELY COVERED BY COBBLES, BOULDERS
FORMER MED. CLINIC
1-3 FT. BOULDER BAR
8-FT. HIGH BOULDER, COBBLE BAR
AGRICULTURALIST'S HOUSE-1957
SEA-WALL WASHED OUT
4-FT. NEW PEBBLE AND BOULDER BAR ON REEF
SEVERE SHORE DAMAGE
LITTLE SHORE DAMAGE
SOIL UNDISTURBED HERE
WELLS
PROTEST. CHURCH
CATHOLIC CH.
FORMER PIERS DESTROYED
LAND SCOURED AWAY BY OUTWASH CHANNELS
ISLET LARGEST CONCRETE BUILDING (TEAM HQ)
SITE OF FORMER KILI VILLAGE
LAGOON
TN
JABOR ISLET, JALUIT ATOLL
1958
0
1000
2000
3000
FEET
DEEPLY CUT-UP
WASH-OUT CHANNEL
ZONE OF BROKEN-UP BEACHROCK
BOULDER 6' X 5' X 10'
BLOCKHOUSE NO. 1
1-2 FT BOULDER BAR
30' X 25' STEEL TANK WASHED 330' SOUTHEASTWARD
CHANNEL SCOURED THROUGH 4 FT. OF CEMENTED CONGLOMERATE
CHANNEL
BOULDERS ABOUT 5' X 6' X 8', THE ONE NEAREST BEACH UPTURNED, TOP HALF WHITE-COLORED, BOTTOM DARK
6-8 FT. BAR
OLD BOMB CRATERS
FLOTSAM ACCUMULATION
BOULDER 5' X 6' X 7'
BLOCKHOUSE NO. 2
COBBLE BAR
CHANNEL
LARGE TANK WITH OPEN TOP
SEVERE LAND EROSION
8-FT. BOULDER, COBBLE BAR
BLOCKHOUSE NO. 3
OCEAN
SAND PATCH
MAN-MADE CHANNEL
8-FT. BOULDER, COBBLE BAR
PEMPHIS BOLES, STRIPPED OF TWIGS, REGROWING LEAVES
H WIENS

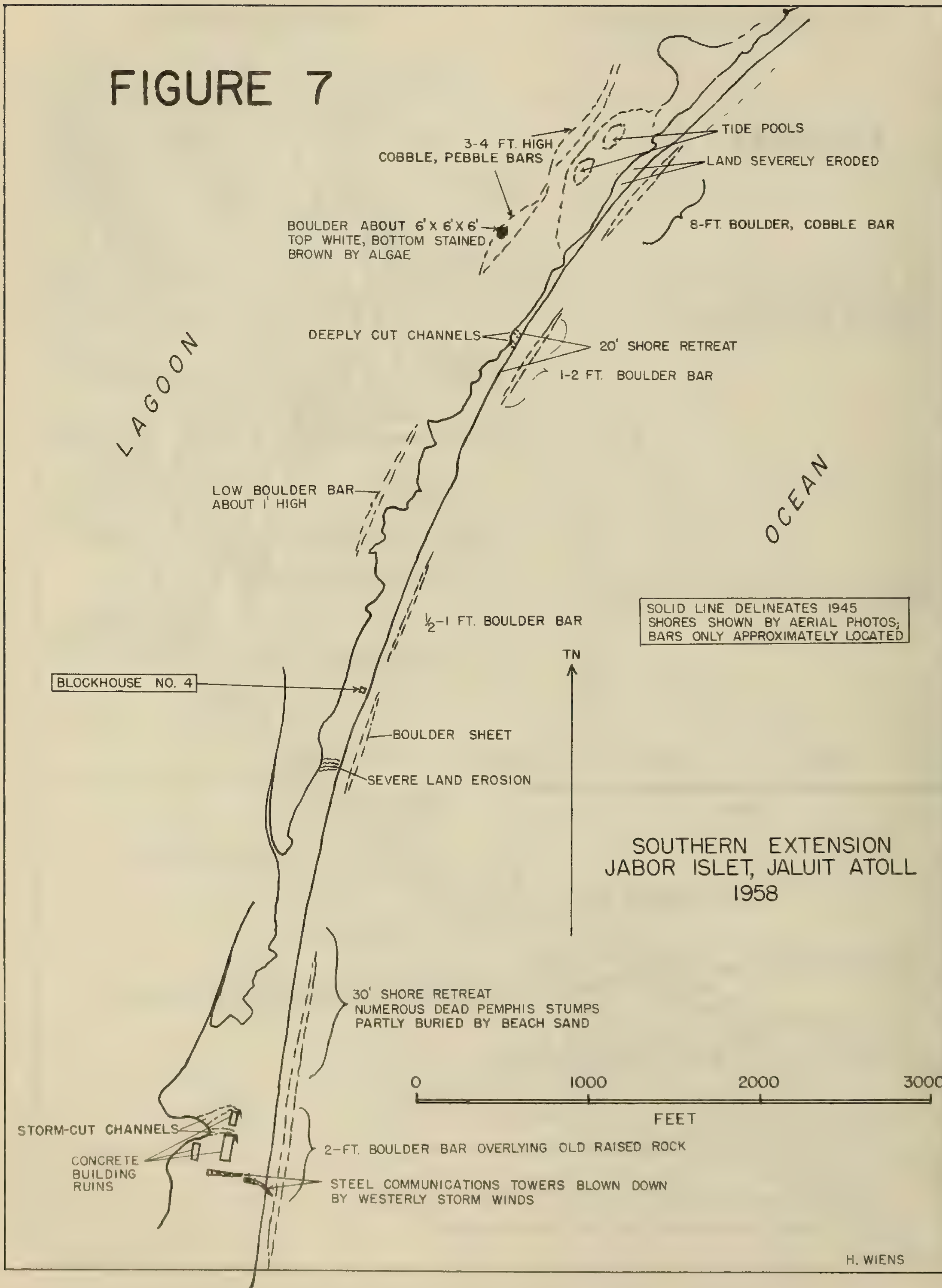
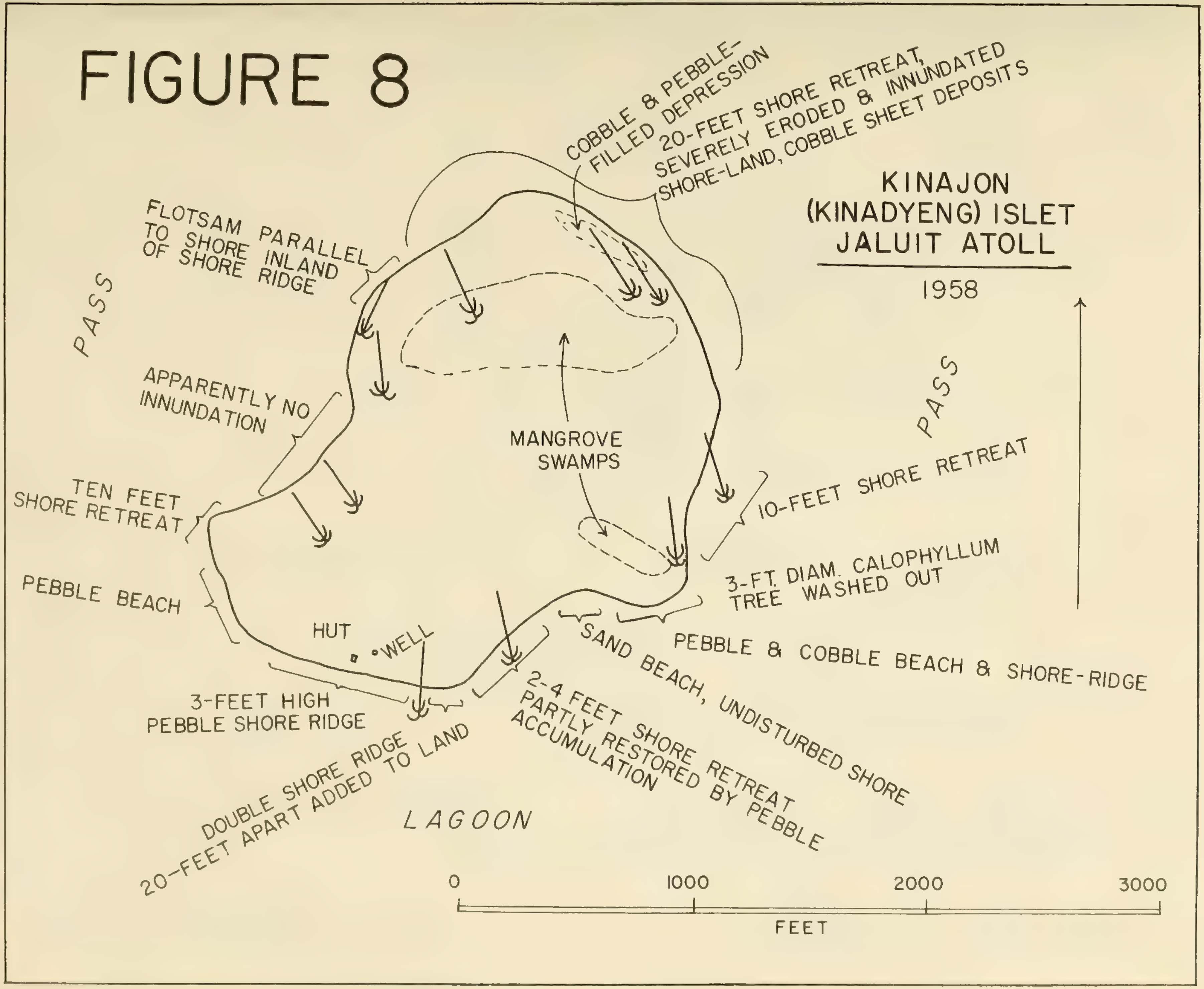


FIGURE 7
3-4 FT. HIGH
COBBLE, PEBBLE BARS
TIDE POOLS
LAND SEVERELY ERODED
BOULDER ABOUT 6' X 6' X 6'
TOP WHITE, BOTTOM STAINED
BROWN BY ALGAE
8-FT. BOULDER, COBBLE BAR
DEEPLY CUT CHANNELS
20' SHORE RETREAT
1-2 FT. BOULDER BAR
LAGOON
LOW BOULDER BAR
ABOUT 1' HIGH
OCEAN
SOLID LINE DELINEATES 1945
SHORES SHOWN BY AERIAL PHOTOS;
BARS ONLY APPROXIMATELY LOCATED
½-1 FT. BOULDER BAR
TN
BLOCKHOUSE NO. 4
BOULDER SHEET
SEVERE LAND EROSION
SOUTHERN EXTENSION
JABOR ISLET, JALUIT ATOLL
1958
30' SHORE RETREAT
NUMEROUS DEAD PEMPHIS STUMPS
PARTLY BURIED BY BEACH SAND
0
1000
2000
3000
FEET
STORM-CUT CHANNELS
CONCRETE
BUILDING
RUINS
2-FT. BOULDER BAR OVERLYING OLD RAISED ROCK
STEEL COMMUNICATIONS TOWERS BLOWN DOWN
BY WESTERLY STORM WINDS
H. WIENS

FIGURE 8


KINAJON
(KINADYENG) ISLET
JALUIT ATOLL
1958
COBBLE & PEBBLE-FILLED DEPRESSION
20-FEET SHORE RETREAT, SEVERELY ERODED & INNUNDATED SHORE-LAND, COBBLE SHEET DEPOSITS
FLOTSAM PARALLEL TO SHORE INLAND OF SHORE RIDGE
PASS
APPARENTLY NO INNUNDATION
TEN FEET SHORE RETREAT
PEBBLE BEACH
MANGROVE SWAMPS
HUT
WELL
PASS
10-FEET SHORE RETREAT
3-FT. DIAM. CALOPHYLLUM TREE WASHED OUT
PEBBLE & COBBLE BEACH & SHORE-RIDGE
SAND BEACH, UNDISTURBED SHORE
2-4 FEET SHORE RETREAT PARTLY RESTORED BY PEBBLE ACCUMULATION
3-FEET HIGH PEBBLE SHORE RIDGE
DOUBLE SHORE RIDGE 20-FEET APART ADDED TO LAND
LAGOON
0
1000
2000
3000
FEET

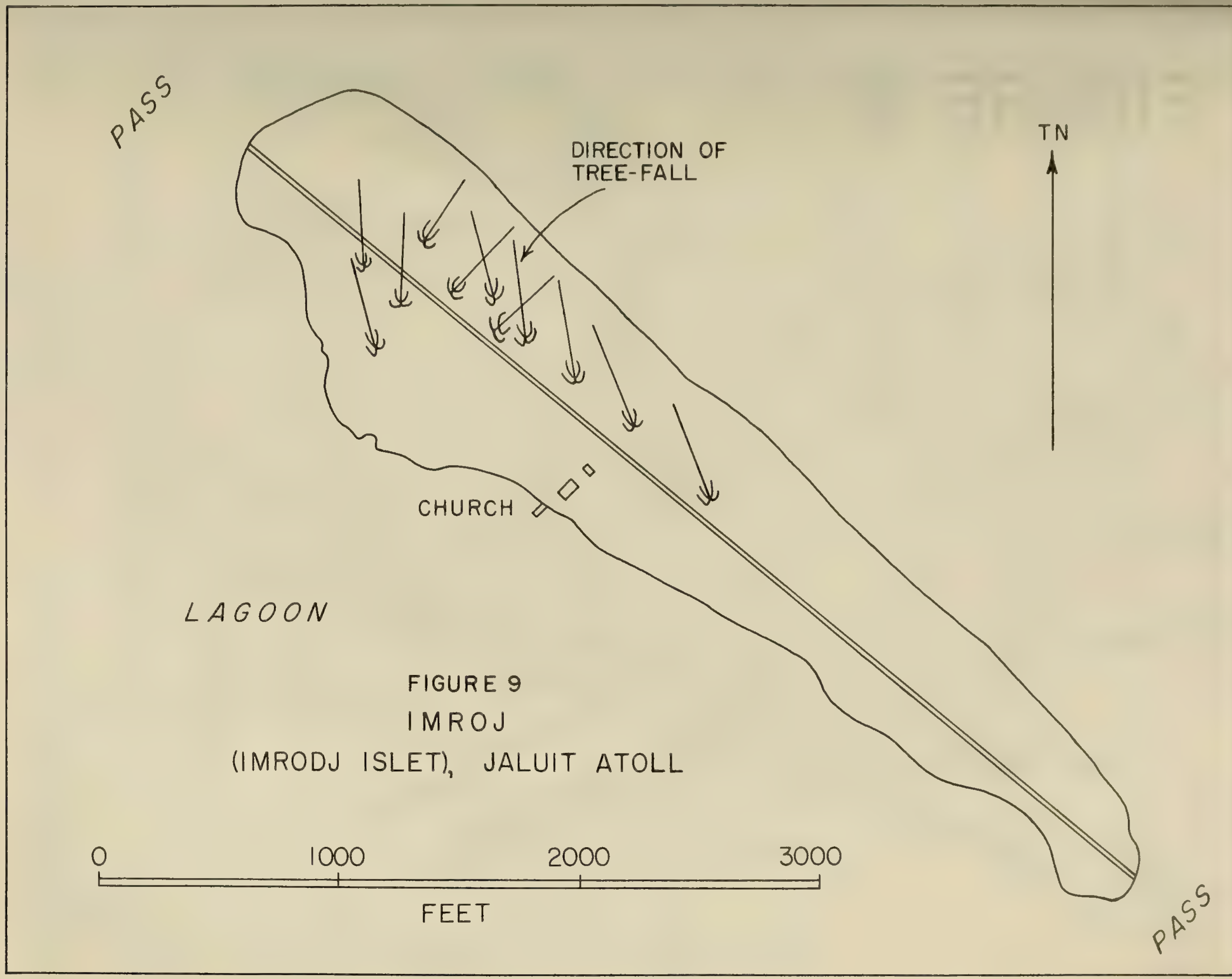


FIGURE 9
IMROJ
(IMRODJ ISLET), JALUIT ATOLL

H. WIENS

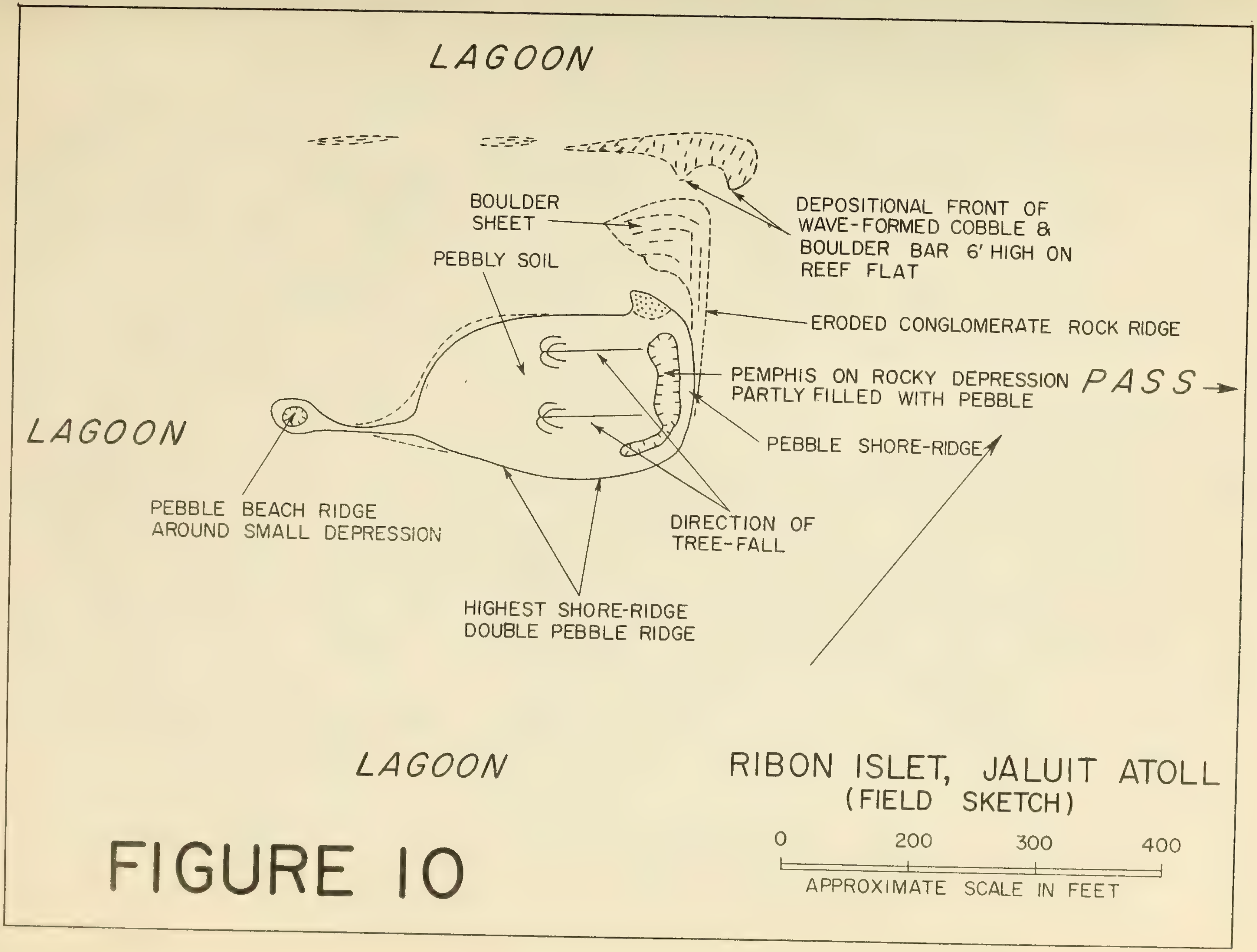

LAGOON
BOULDER SHEET
PEBBLY SOIL
DEPOSITIONAL FRONT OF WAVE-FORMED COBBLE & BOULDER BAR 6' HIGH ON REEF FLAT
ERODED CONGLOMERATE ROCK RIDGE
PEMPHIS ON ROCKY DEPRESSION PARTLY FILLED WITH PEBBLE
PASS
PEBBLE SHORE-RIDGE
LAGOON
PEBBLE BEACH RIDGE AROUND SMALL DEPRESSION
DIRECTION OF TREE-FALL
HIGHEST SHORE-RIDGE DOUBLE PEBBLE RIDGE
LAGOON
RIBON ISLET, JALUIT ATOLL
(FIELD SKETCH)
0
200
300
400
APPROXIMATE SCALE IN FEET

FIGURE 10

MEJATTO ISLET
FIGURE 11

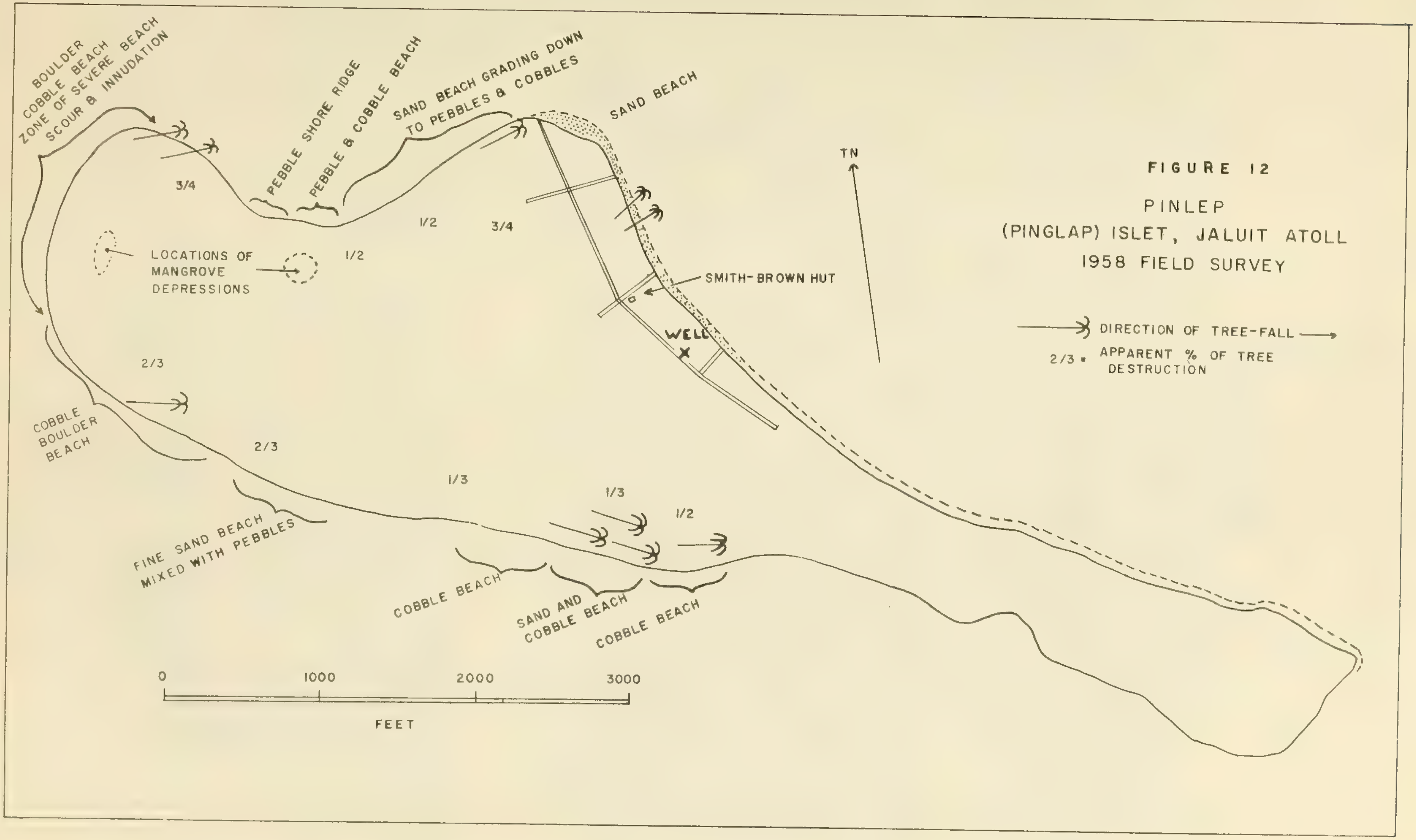
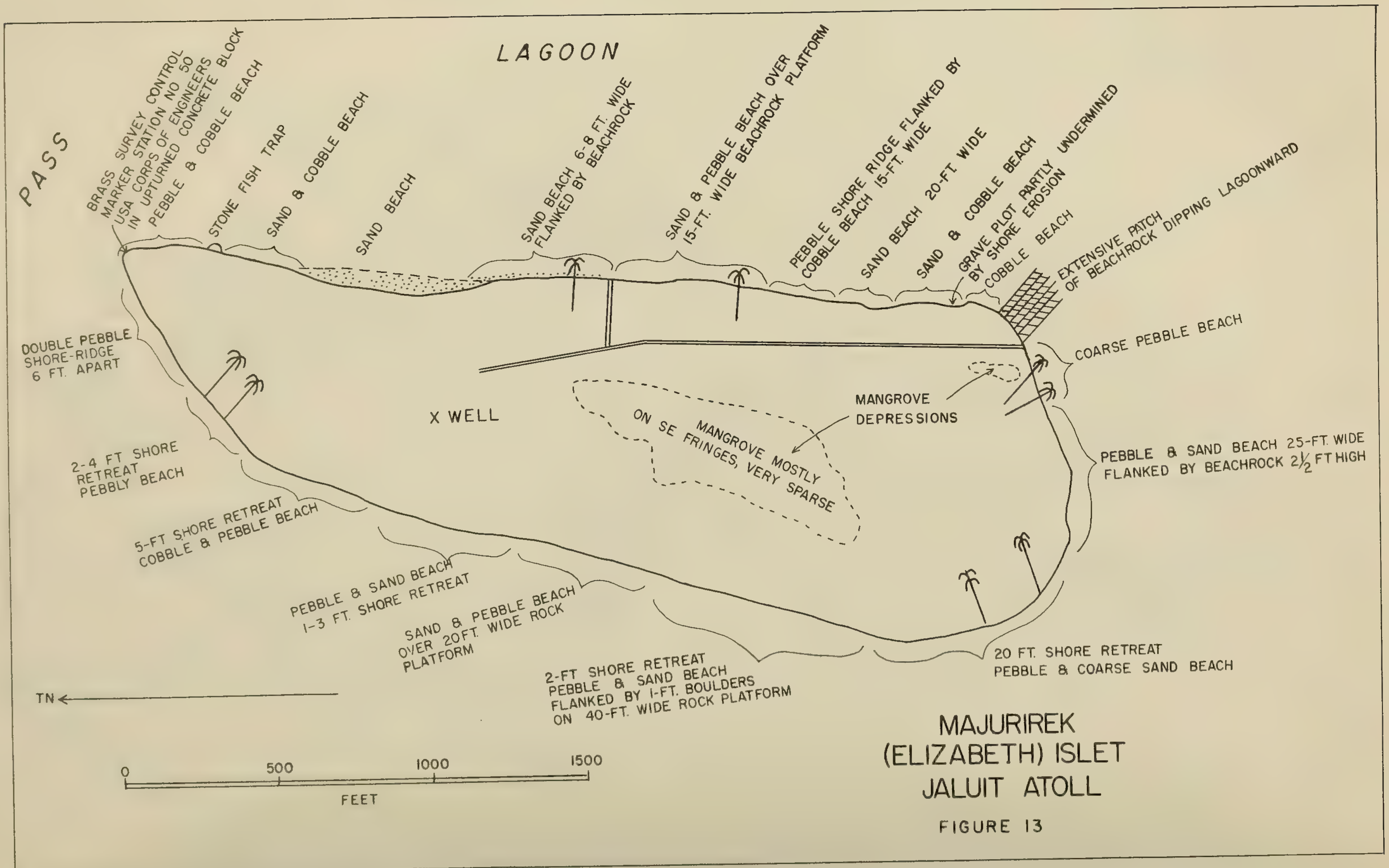


FIGURE 12

PINLEP
(PINGLAP) ISLET, JALUIT ATOLL
1958 FIELD SURVEY



MAJURIREK
(ELIZABETH) ISLET
JALUIT ATOLL

FIGURE 13

III. GENERAL DESCRIPTION OF STORM EFFECTS*

Herold J. Wiens

Direction of wind

Direction of wind from which damage was most extensive to vegetation varies from the northeast to the southwest sectors of the atoll. Roughly, in the northeastern two-thirds of the atoll the direction of tree-fall was towards the south or slightly east of south. In the southwestern third, largely towards the east. While wave and water wash did extensive damage in undermining or washing out tree roots, the overthrowing of the trees and certain structures such as towers and houses also resulted from the wind. Thus, the tree-fall direction may be taken as an indication of the direction of the most powerful or damaging winds.**

The islets of Jabor, Kinajon, Imroj, Ribon, Mejatto, Lijeron, Pinlep, and Majurirek (Elizabeth) were examined by making traverses along the beach and inland from the beach at intervals, and the directions of tree-fall were plotted on large scale maps (Figs. 6-13). On the western reef, Lijeron in the north suffered tree-fall from winds from the due north. At Pinlep, 15 miles to the south, however, the damage in tree-fall was mostly from west winds or winds from slightly north of west. On Majurirek, eight miles southeast of Pinlep, the most damaging winds were from slightly south of west. These same winds moved eastward across the lagoon to blow down two steel towers 150 feet high on the northern part of Jaluit. However, a mile northward toward Jabor on this SE reef the winds were most strong from slightly north of west, pushing lagoon water and carrying from its foundation a steel petroleum tank, 30 feet in diameter (as measured by pacing) and 25 feet high, and setting it on the land 330 feet away in a direction slightly south of east (see Pl. I-c).

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* Note: In this section, Wiens describes the effects of OPHELIA upon Jaluit Atoll. He first presents his general observations and conclusions with reference to wind directions and major changes throughout the atoll. Thereafter, he presents his observations islet by islet. Many of his observations are entered upon the islet maps that he prepared and that comprise the figures referred to in this section. It is intended that these maps be used in conjunction with the text since the maps often contain specific information not included in the text. --D.I.B.

** Blumenstock stresses the first powerful winds rather than the most powerful, and lays more stress on the effects of washing out of roots, see pp. 8-9. Fosberg considers that in addition the energy exerted by the coral-debris-filled waves played an appreciable part in uprooting of trees (personal discussion with Fosberg). --D.I.B.

Northward of here scarcely a mile away the strongest winds were blowing from a north or slightly west of north direction, or directly down the length of the wide part of Jabor Islet from the channel. Similar winds caused the extensive damage observed at Imroj, Kinajon and Mejatto.*

Degree of damage

The heaviest damage to vegetation and soils occurred in the northeast and southeast reef sectors where salt water swept across the reef and land most extensively. Of the islets observed, the most extensive damage probably occurred on Mejatto and Imroj where from 70 - 90 percent of economic trees were blown over (Pl. X-a , Pl. II-c). Jabor and Enejet suffered similar wind and wave force but neither had many coconut or breadfruit trees, and the land here is mostly government reserves. On the other hand, islets mostly affected by the westerly winds were less damaged, largely because of lack of salt water inundation very far inland from the beach. Wind damage also appears to have been less extensive.

In general, the interior of the larger islets and of the wider sections of long islets have less disturbed or undisturbed soil conditions although damage to trees may be just as severe in the middle as along parts of the periphery, depending upon local situations and at times apparently upon the whimsicalities of wind gusts. In the following discussion, islets will be taken up individually.

Jabor

The islet of Jabor is connected to the islet of Jaluit by a continuous strip of narrow land with only small breaks resulting from typhoon OPHELIA. It is difficult to tell, therefore, where Jabor ends and Jaluit begins. The whole section examined and shown in two large scale charts (Figs. 6, 7) will be considered part of Jabor Islet. The section examined by the writer on foot is about 12,300 feet in length from the north end of Jabor southward to the two steel towers where the islet widens. Here are the walls of 3 former concrete buildings, one of large size (150' by 50'). About 4000 feet south of the old hospital tower on Jabor is the remains of a Japanese petroleum storage depot where so-called Sydney Pier was situated. At the base of this pier is a large circular open-top tank surrounded by piled up coral rubble rising about 20 feet. Before the typhoon, two steel tanks 30 feet in diameter rested on circular concrete bases adjacent to the pier base and lagoonward of the large tank.

Between this locality and the wide part of Jabor and between this and the steel towers only the more or less intact remains of former Japanese blockhouses or gun emplacements serve as suitable points of reference. I have numbered these for reference on the maps (Figs. 6, 7) as Blockhouses 1 and 2 north of the tanks and 3 and 4 south of the tanks.

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* See discussions by Blumenstock, pp. 8-9, and by Fosberg, p. 53 for somewhat different views. --D.I.B.

Bar formation off Jabor

Coral rubble bars on the reef flat have developed as a result of the typhoon for almost the entire length of the seaward side of the reef from where Jabor widens opposite the old hospital southward to just past the steel towers (Pl. I-a, b). The highest rubble bars rise to about 4 feet above high tide at a number of places northward of a point about 2000 feet south of the large open tank. This height is indicated by the lack of algal staining in the upper part as contrasted with the brown stain in the tidal lower half. Southward of this point to the steel towers, the rubble accumulations generally are from half a foot to 3 or 4 feet above the reef flat. In the vicinity of the towers, they apparently rest on old beach rock. In the southern sector they form discontinuous strips 20-100 feet wide. Most of the bars are separated from the shoreside beachrock by 50 - 100 feet of the original reef flat. There are 3 stretches of these offshore bars south of the large tank rising to about 4 feet above high tide. North of the large tank there are two other such bars. In each case, the points of highest accumulation adjoin or are opposite storm-scoured breaks across the land from or to the lagoon. The land on the lagoon-side opposite these bars generally appears to have suffered severe erosion of the sediments of which it is constituted.

Since broken glass and other material deriving both from the land and from the lagoon have been found in the seaward reef bars, some of the material in these bars obviously came from the land and lagoon. However, much of the material appears to be derived from the outer reef margin and parts of the reef flat. Slabs of coral rock 2-3 inches thick form imbricated beds on the seaward slopes of the bars, and the landward fronts of the bars have the abrupt terminations of delta talus. Local inhabitants also stated that the bars smelled of rotting reef organisms after the storm, so that fresh materials from the live reef must have formed a large part of the bar. We may conclude, therefore, that the reef margin also suffered severe mechanical erosion from the waves, although much of the debris may have come from the bases and lower parts of the surge channels, as indicated by Banner (pp. 76-77).

So far as the writer observed, few large blocks of rock were torn off from the reef margin and tossed up onto the reef, unless some were buried under the higher accumulations of cobble-size and smaller boulder-size debris in the seaward reef bars. However, on the new bar on the lagoon side about half way between Blockhouses nos. 3 and 4 there is a block of coral about 6 feet in diameter which appears freshly broken off, because the top half standing out of the tides is white and lacks algal staining, while the lower half is only stained light brown where algae have grown between tide levels (Pl. I-d).

Bars are also found on the lagoon reef (see charts, figs. 6, 7), freshly formed as shown by their white coloring. Lack of time did not permit close examination of these. The most prominent bars run in an arc from the large coral block mentioned in the foregoing paragraph to the Sydney Pier base opposite the large tank. A fresh gravel bar also runs roughly parallel to the land strip northeastward from the broken remnants of Sydney Pier.

Just northward of Blockhouse no. 4 a fresh looking bar has formed on the lagoonside somewhat northward of low cobble bars on the seaward side. A new bar was added also to the lagoon reef in the northernmost parts of Jabor between the main pass and the old pier where the rusting hulk of a ship sits on the beach. This runs for about 800 feet in a narrow strip 200 - 300 feet offshore. The materials on it appear to have been derived from parts of the shore near the northern tip of the islet of Jabor and from sediments in the channel fringe.

Of the sections observed, the materials forming the bars were mostly pebbles, cobbles, and small boulders. Very few sand-size particles were apparent in most of the bars. This seems to indicate that most of the finer sediments may have been washed into deeper lagoon or ocean waters and that there was little disturbance of the lagoon bottom where most of the sand and finer material normally accumulate. This accords with the limited bottom inspections near shore by Banner (p. 78), who found the corals under 3-4 feet of water in the lagoon apparently generally unaffected by the storm. However, when the writer examined the same areas on foot in 1956, he found virtually no sand beaches along this entire stretch of land either on the lagoon or seaward side. During the present examination the writer found only one small section of the beach several hundred feet long and about 20 feet wide where fine sand was mixed with coarse pebbles and cobbles. This was on the seaward side not more than 200 - 300 feet northward of the fallen steel towers.

Land erosion and land-build-up on Jabor

In general, although in a few places debris accumulation has widened the land area and has added to the land surface above tide level, the net result appears to have been a significant reduction in the land area suitable for economic plantations. For the most part the old algae-blackened beach rock on the seaward side has remained intact, although here and there the violence of the storm has broken off slabs several feet in diameter, undermined sections of the rock on the landward side or scoured a breach between lagoon and seaward reefs. Undoubtedly the greater consolidation of this generally intertidal rock has served to protect the land in the manner of a low seawall.

Scouring of the less consolidated rock and sediments directly landward of the top of the beach rock in most cases has left a trough between the line of beach rock and the new shore ridge that now runs 10 - 20 feet from the old beach ridge that once adjoined the beach rock (Pl. II-a). At high tide this trough is partly filled with water. This general aspect is observable the entire length of the seaward side from the steel towers northward to where the island widens.

Scouring of this narrow part of the islet, which occupies all but about 3000 feet of the entire 12,000-foot section examined, is more severe on the lagoon side. In some instances this has resulted in channels cut almost or entirely through from lagoon to seaward reef, probably by headward erosion by water pouring over the land from the seaward side.*

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* Blumenstock believes there was primary water movement from seaward but secondary movement from lagoon to sea, see pp.17-18.--D.I.B. [But see also p. 12.--Ed.]

The addition of debris to the land has largely been in a layer from the newly formed shore ridge toward the lagoon (Pl. III-b). This type of debris addition is usually found only where the land widens to 200 - 300 feet or more. In the narrower parts no additional layer occurs on top of the old land surface. On the contrary, a layer of partly consolidated or loose material may most often be observed to have been stripped from narrow and sometimes from wider land surfaces, occasionally with small remnants of the original layers left in the form of platforms.

Especially noted erosional features in this section include a beach stretch 200 feet north of the steel towers where the new seaward shore ridge is now 30 feet inland from the seaward beach rock. Stumps of now dead Pemphis trees stand out of the sand and gravel all the way out to the edge of the beach rock, showing that the vegetated land reached this far prior to typhoon OPHELIA (Pl. III-a).

Lagoonward of the concrete buildings next to the steel towers wave action had washed out a channel from the reef that bifurcates to form two channels cutting inland around the northern sides of the two buildings nearest the seaward reef. The channels each end in a kind of swirl on the seaward sides of the buildings and do not cut all the way across this wide part of the land. The position of the buildings may have tended to funnel the ocean water into a stronger stream causing headward erosion of the land at these places.

Other especially noteworthy washouts of land occurred about 800 feet south of Blockhouse no. 4; at other areas half-way between Blockhouses 3 and 4; 500 feet south of Blockhouse 3, to the north and south of the high mound surrounding the large storage tank, and in most of the areas northward of Blockhouses 2 and 1 in the narrow part of the islet.

The widest channel cut across the land occurs at the north base of the high mound around the large tank (Pl. I-c). Here, at high tide, water runs across into the lagoon in a large stream. A smaller channel cuts through a 4 foot depth of conglomerate about 550 feet north of Blockhouse 2 (Pl. II-b), while still another channel has been cut through as far as the seaward beach rock about 900 feet north of Blockhouse no. 1.

On Jabor proper (the northern 3000 feet or wide part of the islet) the most damaging winds blew southeasterly roughly parallel to the islet as indicated by the direction of tree-fall*. Shore damage was severe all around the island. Inundation apparently occurred over most of the islet, although the soil surface was not much disturbed in the higher middle parts 400 - 500 feet inland from the north end and 300 - 400 feet from the remaining 6-foot high concrete seawall on the northeast side. The seawall was broken in its southern 200 - 300 feet as far as the triangular concrete structure which dates back to German times. The deposition of gravel and rocks was much reduced by the protection of the seawall along

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* For different estimates see Blumenstock, p. 8.
-- D.I.B.

the northeast side. Beginning with the triangular structure, however, gravel sheet deposition with a front depth of up to three feet advanced inland 200 - 300 feet from the seaward shore ridge as far south as the building occupied by the expedition and by the agriculturist. From this building southward the entire land surface has been strongly disturbed either by scouring or by deposition. The surface is covered with pebbles, cobbles and small boulders up to 6 inches thick and 1 - 2 feet in other dimensions. Except for the toppled trees and still standing trunks of Pandanus the scene looks like the bed of a rocky river. Only a few strips and patches of the original soil surface are identified by occasional growths of grasses such as Lepturus.

On the lagoon shore, the two stone and concrete piers on which the government generator equipment and a warehouse stood now are merely piles of coral rubble that protrude into the lagoon. The former 4-foot high seawall of cemented coral blocks along the lagoon shore has been stripped down to remnants 1-2 feet high, and at the north end some 200 feet of it has been torn off and upturned altogether. Rubble from the lagoon reef flat and shore has been scattered inland 30-50 feet in the northern half of the islet. The greatest piling up of coral rubble has occurred on the shore facing the channel, for the most damaging winds blew directly inshore across the channel from the north and hit this coast area squarely*.

Near the bend in the seawall on the eastern part of the channel shore a 50 foot break in the wall allowed the storm waves to scour out a semi-circular hollow backed by a curved shore ridge of pebbles, with additional debris spreading inland from it. At the northern point of the islet the seawall is buried by a gravel and rubble shore ridge that rises to the highest peak of any seen on the various islets, about 10 feet above low tide. This ridge slopes channel-ward in a gravel beach out about a hundred feet and drops off into deep channel water. Since, prior to the typhoon, the bottom at the base of the seawall dropped off quickly into the depths of the channel, the amount of debris filling in the channel fringe here is considerable. The shoaling of water in this area and westward across one of the branch channels has made it hazardous for ships to enter by the most direct channel to the Jabor anchorage, and forces ships such as the Roque to use the more northerly channel running northward past Enejet.

Inland, rubble has been deposited in a two-foot depth around the concrete walls of the agriculturist's former home completed just two years before the typhoon and situated 100 feet from the seawall. Farther inland, however, the ground surface is little disturbed, and ornamental croton hedges continue to flourish, although most of the trees are blown over.

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* For differing views, see Blumenstock, p. 8.
-- D.I.B.

Soil and vegetational damage on Jabor Islet

In general, 95% of the trees on this islet were toppled or snapped off at varying heights above the ground. From the concrete house in which the expedition stayed southward, virtually none of the original ground surface and ground vegetational cover remain except at small high spots such as the slope up to the large storage tank. In this area coconut trees still may be found growing at widely separated intervals. Almost all Pandanus appear to be killed, although the prop roots and part of the lower trunk may remain. No trees of large size grew in this area except near the Expedition Headquarters. These are mostly Calophyllum, and they have been toppled, with their great shallow root systems standing high in the air. Some of them have re-sprouted leaves on a few limbs, since the trees often retain a few roots still buried in their growing positions. On a number of the wider rocky platforms of the islet, however, the hardy Pemphis, stripped of smaller branches and twigs and left with vertical trunks 1 - 2 inches in diameter, has begun sprouting leaves on these remnants (Pl. VIII-c) and will no doubt soon be essentially recovered.

On the wide northern part of Jabor a few large Calophyllum trees near the base of the northern pier have not been uprooted and are sprouting leaves from trunks and large limb remnants. All the Casuarina trees which were up to 6 - 8 inches in trunk diameter were uprooted by wave wash and wind* and most of the other large trees and the coconut and Pandanus trees were uprooted or killed by trunk snapping. However, shrubs, weeds and grasses over most of the interior in an area 500 feet wide by some 1000 - 1500 feet long appear relatively undisturbed and similar in aspect to what they were in 1956.

Damage to structures

In general, all wooden buildings were demolished and thatched houses smashed flat by the wind. Some roofs were pulled back into position and are temporarily used. All houses require rebuilding, however. Concrete structures stood up well although the lower stories were inundated and doors and windows washed out. Cisterns mostly remained intact, but were contaminated.

Kinajon Islet

This islet stands between two of the channels of the Northeast Pass and across the channel southeast of Imroj Islet (Fig. 1). It is an oblong islet about 2500 feet in length by about 1500 feet in width at the widest part (Fig. 8). Much of the northern third of the islet appears to be occupied by a depression partly overgrown by mangroves. A smaller mangrove depression also is found in the eastern bulge of the islet. The southwestern third formerly (during World War II) contained some Japanese vegetable gardens covering about an acre in the middle. This area has fewer trees and a more open aspect.

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* But see Fosberg, p. 54.-- F.R.F.

The north end of the islet with the large mangrove swamp faces the seaward reef. Coral debris up to small-boulder size was carried inland by storm waves as much as 50 - 100 feet along the northern third of the shore-line, filling the seaward parts of the large mangrove swamp with gravel. The front of this deposit is 2-3 feet high. This deposition did not occur at the channel sides of the islet in the wide western indentation or along the eastern and southern shores. The latter two sectors were in the lee of the waves. The western channel escaped such inshore deposition possibly because of lack of reef shoaling from the deep channel and perhaps because the waves may have run more parallel with the coast than across it.

The beach sediments deposited by the storm in the western indentation are mostly sand and silt with small amounts of pebbles. The only other beach with similar sandy character is a small section 150 - 200 feet long directly southwest of the eastern bulge of the islet. The beach in the northern third of the islet is composed of coarse pebbles, cobbles and small boulders. In the rest of the shoreline small to medium size pebbles form the beach and shore ridges.

Erosion of the original shore appears most severe in the northeast sector where a 20-foot wide strip inland from the old beach rock has been scoured away and the new shore ridge moved this distance inward. At the southwest end erosion has eaten away about 10 feet of the original land along the shore, and about the same amount of erosion occurred as a result of the storm in the northeast sector just north of the eastern bulge of the islet. In the southern leeward and lagoonward sectors, however, an initial scouring of the shore washed out the roots of strand trees. Subsequent to this, pebble and cobble deposition has added a 10 - 20-foot wide strip of loose sediments to the shore. In the southeast lagoonside bend of the islet there are two shore ridges or storm ramparts 20 feet apart, and the strand trees blown over by the storm are partly buried by sediments.

The tree-fall direction in most parts of the islet was slightly east of south.* The largest percentage of tree destruction appears to be in the northern peripheral areas where an estimated 90% of the trees were uprooted. The largest percentage of trees left standing and growing appear to be around the small mangrove depression in the eastern bulge of the islet. Here about one-half of the coconut trees remain standing with growing fronds.

In most of the rest of the islet between 60 - 75% of the trees were felled. The taller mangrove trees had their foliage stripped off the top half, and some are dead, but most of them are forming new leaves. The smaller lower mangroves appear little damaged and relatively flourishing.

Except for the parts of the periphery of the islet damaged by gravel deposition, by storm wave scouring, or by uprooting of trees, the ground cover of low plants such as grass, weeds and shrubs appear to have been affected by the storm.

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* No one dominant direction according to Fosberg, notes. --D.I.B.

Imroj Islet

Imroj lies across the pass northwest from Kinajon and is about 4,200 feet long by 1000 feet wide 1000 feet from the northwest end, and about half this width in the southeast half (Fig. 9). It was and is the principal inhabited islet presently having about half of the atoll's population. Prior to the storm it had a very luxuriant aspect, with dense plantings of coconut, pandanus and many breadfruit trees.

Marked shore-line changes have occurred all around the islet. The old pier was not very well built and consisted mainly of uncemented coral blocks piled up in a regular line covered by coral sand and silt. This is now merely a mass of coral blocks protruding lagoonward into water of 4 - 6 foot depths.

The greatest shore and land damage has been on the seaward or northeast side. The islet extends roughly northwest to southeast, and the most damaging winds came from the northwest at a diagonal across the islet, as indicated by the direction of tree-fall.* Violent beach and shore scouring occurred on the seaward side, and pebbles, cobbles and small boulders were carried inland and deposited 50 - 150 feet from the old shore ridge. The mangrove depression at the northwest end is partly filled with gravel.

Water from the ocean scoured several shallow depressions across the lagoonward half, in the southeastern two-thirds of the islet. The closeness of the coconut and *Pandanus* plantings and the depth of root penetration made the soil disturbance unusually great. Each overturned tree resulted in the pulling out of a great mass of soil and gravel by the densely massed roots and the excavation of large holes 2 - 3 feet deep and 6 - 8 feet in diameter. The result is an extraordinarily rough surface which presents a very difficult problem in the replanting of the islet.

Vegetation damage

An estimated 90 to 95% of the economic trees were uprooted by the storm and a large part of the ground cover was killed on the seaward half of the islet.

House damage

All houses on the islet were demolished. Some reconstruction has been done through the use of scrap material from the old structures, but many of the people still must live in the most make-shift shelters. The materials for thatch-making are available only in very small quantities since most of the *Pandanus* and coconut leaves were destroyed by the storm, and few are growing.

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* North to northeast according to Fosberg (notes) and Blumenstock --D.I.B.

Ribon Islet

Ribon is a tiny islet about 450 feet long by about 250 feet wide oriented northeast to southwest (Fig. 10). A strip of beach rock runs roughly at right angles to this direction from the middle of the northeast beach northwestward for about 500 feet. Small boulders and gravel form a sheet up to a foot in depth near the northwest end of the beach rock strip and about 100 feet in diameter. A few yards farther northwestward a pebble and cobble bar about 60 feet wide rises to about 6 feet above the reef flat and runs at lower heights and narrower widths in three discontinuous strips in a southwesterly direction. This bar appears to have been freshly built by the typhoon waves.

The northeast end of the islet faces the pass opening to the ocean, and a 20-foot wide strip of the former land appears to have been scoured away between the old beach rock and former shoreline and the present shore ridge. Pebbles and cobbles have been washed inland and partly fill a rocky depression about 100 feet wide and 300 feet long running parallel to the northeast shore. A thriving stand of shrubby Pemphis grows on the rock of the depression.

At the southwest end of the islet a cobble and gravel spit has been built lagoonward for a distance of about 220 feet in a strip 5 - 6 feet wide and up to about high tide level or slightly above. At the landward end the current eddy of the storm waves apparently swirled to form an oblong to circular rampart or beach ridge around a depression 1 - 2 feet below the ridge level and filled with flotsam.

The islet has a high shore ridge all around it formed of pebbles and cobbles. In the southern half of the islet there is a double shore ridge which rises to the highest level on this side of the islet. While the strongest storm waves appear to have come from the north and piled up the 6-foot bar on the reef flat in this direction, the direction of tree-fall was to the southwest, indicating a wind of maximum violence from the direction of the open pass or northeast. The position of Mejatto Islet and of the pass may have influenced somewhat the apparently differing direction of the tree fall both on Imroj and Mejatto from that on Ribon. The protection afforded by Mejatto situated to the windward (with reference to the storm) of Ribon, also may have resulted in the decreased tree damage. Some 6 - 10 coconut trees were downed, 14 were left standing and growing. Most of the Pisonia trees still have their trunks and chief limbs intact and are regrowing leaves. Guettarda and Scaevola growing among the rotting old coconut stumps and Asplenium nidus continue to flourish in the interior of the islet. So little disturbance on such a small islet can only be attributed to its geographic position relative to Mejatto Islet and the open pass.

Mejatto Islet

Mejatto Islet is about 12,500 feet long and from 450 - 600 feet wide, although near the northern end it widens to over 2,200 feet (Fig. 1). Its long axis is roughly north northwest to south southeast. It lies north of the pass NW of Imroj (Fig. 1).

This islet suffered even more from wind and wave destruction than Imroj. With the exception of about the northern 2000 feet and 500 - 600 feet on the southern end, the entire islet appears to have been swept by ocean water and severely eroded and cut up. Gravel sheets were laid over large parts of it from the seaward side half to three-quarters of the way across the islet. Many channels were cut across the islet.

Coconut, Pandanus and other trees not only were blown over and washed out but a large number were washed into the lagoon where many stumps are visible on the lagoon reef and many trunks stand in the deeper water of the lagoon slope. From 1 to 4 feet of the original soil were washed from much of the islet although in other areas 1 - 3 feet of gravel cover the original surface (Pl. II-d, Pl. X-b).

A map for plotting data directly was not made before going to this islet. Instead a traverse line by plane table was made by Blumenstock and the writer down the length of the islet southward from a point 3000 feet from the north end, and notes were taken along the route of the traverse which was measured by pacing (Fig. 11). Most of the traverse route was near the seaward shore-ridge. The return trip to the point of origin w s made separately by Blumenstock and by the writer, who paced the last leg of the traverse (2475 feet) alone and returned along the lagoon side of the islet pacing only the first 500 feet from the south end. The features noted on the map of Mejatto (Fig. 11) thus are less exactly located and less correctly oriented than on the other maps made by the writer.*

At the starting point a very large Calophyllum tree standing at the lagoon shore has survived the storm. Its branches were broken back to the few remaining main limbs, but leaves are sprouting again from them.

Immediately to the south of this tree ocean water had poured across and scoured out a large channel across the islet. Coral debris from this area forms a convex bar on the lagoon side reef enclosing a shallow pool. Many similar bars and pools occur along the length of the islet opposite other channels cut across the islet so that the bars give a scalloped appearance to the lagoon side.

At station 3 (700 feet south of station 1) the land is badly eroded and many coconut tree trunks still standing have lost their crowns. A channel is almost cut through to the seaward reef by headward erosion and is about 150 feet wide.

At station 4 (560 feet south of 3) the erosion channel makes a 90-foot break in the ledge rock at the seaward side and a hole filled with water at low tide is scoured out landward of the beach. Two to three feet of the original surface are stripped from the seaward half of the islet, leaving high mounds of gravel where Pandanus or coconut roots remain in place.

A characteristic feature on this islet is the scour-pit formed on the down-stream side of the tree stumps opposite the accumulation of gravel and flotsam on the upstream side (see McKee, p. 40).

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* Traverse distances given are, I believe, correct within 10% --D.I.B.

While the lagoon sides of islets most often have sand beaches, Mejatto's sand beaches (if there were any) appear to have been washed away into the lagoon leaving only pebble and cobble beaches. Washed out tree stumps are numerous on the shallow lagoon reef and slope between stations 4 and 5.

The distance between stations 4 and 5 is 365 feet and between 5 and 6 it is 825 feet. About 200 feet south of station 5 is a barren wash or channel cut through, with no vegetation left. In this area a blown over Barringtonia tree 2 feet in diameter is sprouting a few leaves from the trunk. Some 550 feet south of station 5 a channel working headward from the lagoon side has left a V-shaped indentation. On the seaward side is a low spread-out cobble and boulder bar. The land between sea and lagoon, here about 275 feet wide from shore ridge to the channel head, is badly eroded and pitted and extremely hummocky. Some 3-7 feet of the soil and gravel have been removed.

In the vicinity of station 6 three trees with wide buttresses, which are probably breadfruit, are still standing upright but have had branches, bark and leaves stripped and appear dead. Many coconut tree stumps lie on the lagoon reef.

At station 6 there is another lagoon outwash channel-indentation, and at the mouth of it lies a dead breadfruit tree trunk with roots and some limbs. Near the lagoon close to a standing breadfruit tree trunk and two lagoon shore Calophyllum trees a patch of the original soil, black humus mixed with sand, remains. Lepturus grass growing in a thick mat on this soil apparently survived the typhoon inundation.

Stations 6 and 7 are separated by 550 feet. Two discontinuous patches of bouldery rubble lie off the seaward beach here but are not heaped up sufficiently to constitute bars. Stations 7 and 8 are 550 feet, and 8 and 9 are 825 feet apart. In the vicinity of station 9 there appears to have been a large breadfruit grove prior to the typhoon; 10 - 12 large trees with buttressed trunks and limb sections still standing indicate the remains of this grove. Much flotsam has been accumulated around their bases.

Station 10 lies 1310 feet south of station 9 and from station 10 to the southeast end of the islet is 2475 feet. North and south of station 9 on the seaward reef from 5 - 150 feet offshore are patches of scattered coral cobbles and small boulders.

Between stations 9 and 10 there is an extensive scoured-out backridge trough inshore from the new pebble shore ridge. The central part of the islet rises to about the ridge height or more and is covered by a sheet of gravel. Most of the coconut and Pandanus trunks and stumps have been uprooted and washed lagoonward. Few remain standing.

This general aspect is found southward over most of the area between station 10 and the end of the islet, except for the last 500 feet. Around the curve of the shore lagoonward of the pass between Mejatto and Imroj two pebble and cobble ridges flank the shore, the inner one about 20 feet inland. The lagoon half of this part of the islet has retained

much of its original vegetation. Part of the area is occupied by a mangrove depression separated from the lagoon only by a pebble shore ridge.

There are two or three separate depressions in which mangroves are growing in this part of the islet. The one nearest the end of the islet is partly filled with pebbles and cobbles washed in from the seaward side (Pl. III-c). Many of the small mangrove trees appear to have been broken off but some stalks are still alive and have re-sprouted. Many low young coconut trees also have survived in this area. Northward of the southern mangrove depression and its surrounding trees there has been considerable erosion of the land back of the lagoon shore. A pool 3 feet deep and 20 by 50 feet in horizontal dimensions has been scoured out and many coconut palms overturned but not washed from the site of growth.

In this vicinity and adjacent to an outwash channel-indentation stands a concrete cistern with brackish water. It was sunk 2 feet into the ground with the walls rising 2.5 feet above the old ground level. Here the surface of the ground is not greatly disturbed. Northward of this the soils are badly eroded and cut up. Approximately opposite station 7 but on the lagoon side of the islet is another mangrove depression elongated parallel to the axis of the islet. Pebbles and cobbles have filled in about three-fourths of the depression from the seaward wash to a depth of about three feet (Pl. III-d).

The extreme northwest end of Mejatto was not visited by the writer, but a view from the schooner in the lagoon showed many more coconut and other trees to be standing here. Obviously, less wind and water damage had occurred in this widest part of the islet.

Lijeron Islet

This small islet on the northwest reef measures an estimated 300 by 600 feet but was not paced off.

On the east end a sand beach 50 feet wide borders the islet. The north and south sides are concave indentations protected from the normal waves from the east and have developed beach rock. At the west end there is a narrow neck of rock extending to a rock platform less than half the size of the eastern part of the islet and supporting a pure dense stand of *Pemphis*. This contrasts with the almost pure stand of *Pisonia* on the eastern and larger and higher part of the islet. A few *Cordia* and *Tournefortia* trees and perhaps half a dozen coconut trees also are on the eastern section. There appears to be little significant topographic change resulting from the storm save possibly the development of a long sand hook southward from the eastern sand beach. Some sand was spread in a sheet half-way across the islet from the north.

The vegetation on this small islet also survived well. A few *Pisonia* and *Cordia* and 2 - 3 coconut trees were toppled, the direction of fall being due south.

This isolated uninhabited islet is the nesting place for hundreds of white-capped noddy terns which are relatively tame. Most of the nests contained a young chick or an egg at the time of our visit. Overhead circled many terns and frigate birds.

About a dozen terns and one young frigate bird were caught by the Jaluit islanders from our schooner to take home for eating. Some eggs also were collected apparently for the same purpose.

Pinlep Islet

Pinlep Islet is situated on the west reef of Jaluit (Fig. 1). Between the islet and the lagoon proper is a faroe or secondary lagoon of relatively shallow depths resulting from the upbuilding of a reef enclosing a triangular body of water. The northwest shore faces a wide reef flat, but the oceanward reef to the south is narrow. The islet is about 8,500 feet long. The eastern half runs between 500 and 800 feet in width. The central portion of the western half is widest, about 2,200 feet. The main inhabited parts appear to have been along the lagoon-facing sectors of this wide portion (Fig. 12).

Our small boat made a landing near the middle of the islet after crossing the secondary lagoon. The schooner had to stand some distance off the reef of the secondary lagoon so as not to drift onto the reef, since the wind blew toward this reef from the east.

In an interview with the oldest inhabitant, named Brown-Smith, we were informed that the first severe storm wind of the typhoon blew from the north starting at about 6 p.m. By about 10 p.m. the wind had shifted to blow from the south with great violence. Our informant stated that it was this wind that blew down most of the trees. However, almost all the trees downed had fallen in an easterly direction, so that the most violent blow must have come from the west. If the first violent winds were from the north followed by violent west winds, as the tree-fall appears to indicate, the cyclonic whirl must have moved westward and then northwestward.

The most severe damage inflicted on the trees appears to have been near the western end of the islet where an estimated two-thirds to three-quarters of the coconut, Pandanus, breadfruit and other trees were killed. The central part of the south and seaward sides of the islet appear to have had the smallest proportion of the trees toppled, between one-third and one-half. The writer did not traverse the eastern half of the islet and cannot describe the extent of damage in this portion.

Along the beach north of the Brown-Smith hut, coconut trees were bent over northeastward, but were not completely overturned. Many breadfruit trees were toppled over along the village road parallel to the lagoon beach. Others remain standing but have most of the limbs broken off. These and others with some large roots still in the ground are sending out new leaves. Near the northwest beach a mangrove stand in a mucky depression has most of its trees stripped of leaves and twigs, and the

trees appear dead. The northwest facing shore here is badly eroded and has retreated 10-15 feet. The character of the beach sediments along the shores observed are shown in Fig. 12.

Inundation was most severe and penetrated farthest inland at the west end of the islet, where the shoreline appears to have been scoured back 10-15 feet, while water-borne sediments and flotsam were carried in forty feet or more from the shore ridge. On the southerly section of this western end many Guettarda, Scaevola and Tournefortia, toppled over but only partly washed out, are sending out profuse leaf sprouts. About 1500 feet from the west end a breadfruit tree trunk still standing 80-90 feet high is sprouting leaves from parts of the large limbs remaining, although all smaller branches are gone. Along this south shore there appears to have been little salt water penetration inshore.

Majurirek Islet

Majurirek Islet is roughly 3000 feet in length (Fig. 13). Its long axis is aligned almost due north and south. Its greatest width, about 1100 feet, is near the south end, and it narrows gradually northward until at about 500 feet from its northern tip it has a width of some 600 feet. A mangrove depression about 1000 feet long by 250 feet wide occupies the south central interior of the islet. However, only sparse patches of mangrove are found, largely near the southeast fringes. Most of the depression is an open pool of salty or brackish water. A much smaller mangrove depression occurs near the southeast shore of the islet just west of the village path.

The character of the shore and beach areas at the time of the visit by the writer is shown in Fig. 13. In general, the severest storm winds of Typhoon OPHELIA came from the west, as indicated by the plotted direction of tree-fall in the chart. This accords with the observations made on Pinlep, also on the west reef, as well as with the observations made in the southern extension of Jabor Islet where the steel towers were also blown down in an eastward direction. Locally, the directions of tree-fall were not always toward the east. In a few instances where strand trees were undermined by wave wash the directions of fall were toward the beach. On the ocean side in the extreme north shore area the dominant direction of tree-fall appears to have been toward the southeast. In the southwest shore area the direction of tree-fall seems mainly somewhat north of east. At the southeast end the tree-fall was toward the southeast. Along the lagoon shore the direction was dominantly lagoonward or eastward.

Of the islets examined, this one appears the least changed morphologically along the shores. Inundation by ocean or lagoon water appears to have been restricted to a narrow zone of a few yards from the shore and only occurred locally. No significant amount of sediment was washed inshore, and the shores were only slightly scoured. Beach character probably was changed, but, without information on the nature of the beaches before the storm, the writer cannot evaluate this change. Shore retreat owing to wave-scouring occurred on the lagoonward side of the southeast bend of the islet about 100 feet north of the beach rock formation. Here an old family grave-plot was partly eroded away. The maximum retreat appears to have occurred just at and just south of the northwest

bend of the seaward shore, where from 3 to 5 feet may have been scoured away from the shore. In the southern half of the seaward area, shore retreat appears to have been less than two feet. This is the only islet aside from the small Lijeron islet ("Bird Islet") where a considerable sand beach development was observed or retained. Characteristically, this sand is on the lagoon beaches, some of it overlying beach rock.

In the interior the only morphological change resulted from the excavation of holes or pits when falling trees brought out with their root clumps large amounts of gravel and soil held by the roots. Since many trees were toppled, the topography is very uneven where this occurred. Pandanus trees were mostly snapped off below their crowns, with roots and main trunks still standing although dead. Where they were killed, coconut trees tended to be uprooted rather than snapped off below the crowns. Many of the breadfruit trees likewise had all major limbs broken off, but the trunk with remnants of limbs remains standing, with roots still in situ. Where this occurred, the tree trunks and remnant limbs are re-sprouting leaves. Even those breadfruit trees that were overturned but which retained some large roots underground are re-growing leaves.

In terms of the most important tree types, the Pandanus suffered most destruction, up to an estimated 90% of these trees being killed on most of the islet except along the lagoon shore where low young trees suffered less damage. The coconut trees at the south end of the islet between the large mangrove depression and the shore suffered up to two-thirds loss. North of the large mangrove depression about half of the coconut trees were toppled. A large grove of large Pandanus occupied the area west of the northern third of the large mangrove depression. Almost all had their crowns and limbs snapped off. Further damage had been inflicted in this area by uncontrolled burning of the fallen fronds and trees. This burning also affected coconut trees still living and some young coconut sprouts.

The mangrove and Pemphis trees fringing the southern end of the mangrove depression appear little damaged by the violent wind. Bananas blown over and killed in the northeast quarter of the islet have re-sprouted young plants from their roots.

Salt water from the oceanside during high tide probably infiltrated the mangrove depression, because the land area west of the depression is made up of boulders up to 8-10 inches in diameter and probably allows relatively free water movement through it.

Where the small-boat from our schooner landed, about 350 feet from the southeast bend of the islet, two large Calophyllum trees and one large Hernandia sonora tree remain growing on the strand, having re-sprouted leaves from the branches and trunks.

In conclusion, it appears that of all those islets examined by the writer, Majurirek escaped with the least damage to its soil and economic plants.

IV. ISLAND STRUCTURES AND THEIR MODIFICATION

Edwin D. McKee

Development of islet strata

The peripheral reef of Jaluit Atoll, like that of other atolls, is composed of rigid, wave-resistant skeletons of corals and coralline algae, with clastic particles or unbroken shells and skeletons of benthonic organisms partly or entirely filling cracks and interstices. In contrast, rocks that rest upon these reefs and that normally form the islets rising above them are very different structurally and texturally. Such rocks consist entirely of accumulations of detrital materials, ranging from sand to boulder size, which are cemented to varying degree. These rocks may or may not exhibit well-developed stratification. Bedding is poorly defined and inconspicuous where coarse material has been laid down in broad sheets or as mounds; it is prominent and in the form of cross-stratification where the normal sorting processes of a beach have been responsible for its development.

The forming of islands upon the peripheral reefs of atolls generally is attributed to the accumulation of detrital debris, at a particular stand of sea level, following initial development of a surface irregularity or nucleus for concentration. Should sea level rise suddenly and appreciably, a probable result would be rapid upward growth of reef-forming organisms so that even the former island area might be covered with the new reef rock; should sea level go down the island doubtless would be destroyed by subaerial processes of erosion. With a relatively constant position of sea level, however, an island may be expected to develop, within certain limits, as a result of geological processes operating under two types of conditions: (1) the normal, day by day processes of deposition and erosion resulting from waves, tides, longshore currents and other regular controls; (2) the occasional great storms which act violently and abruptly modify the environment.

To interpret correctly the history of any particular islet on an atoll, the processes operating under each of the two conditions cited above must be understood and appraised and criteria must be established for recognizing the deposits formed in each instance. Clearly, most islets are formed of deposits representing both normal and storm conditions, but the proportions attributed to each on any particular islet vary widely.

In general, the deposits of normal sediments on an islet consist of sand and small gravel with good sorting and well-developed cross-stratification. Constant reworking by waves and tides tends to remove the very fine materials (below sand size) and to separate fine gravel and sand into distinct layers. Because permanent accumulation of sediments is largely in the lee of the islands, such sediments continuously contribute to a leeward extension of beach deposits and therefore islets normally build in that direction.

Islet deposits developed during major storms, in contrast to those formed in normal times, consist dominantly of gravel, including much of boulder dimensions, that appears to be the product of mass or collective movement. They form ridges along the windward shores and sheet or blanket deposits across large parts of islet interiors. They may also form temporary ridges out on the reef flat. In general, these deposits are characterized by relatively poor sorting and rude stratification, but commonly by fair to good imbrication among flat gravels. Removal of sand-size and smaller particles through winnowing action is normal.

The past history of certain islets on Jaluit Atoll can be deduced in part through examination of sections both in natural exposures and in man-made wells and trenches. On the islet of Jaluit, at Jabor, for instance, exposures in a section (Figs. 14, 15B) across the northeastern part, immediately southwest of the inhabited area, show consolidated, cross-stratified lime sandstone and lime gravel, with laminae dipping lagoonward, only 350 feet from the present seaward margin of the islet as well as near the present lagoon margin. These once-buried remnants indicate the extent to which beach sands have migrated across the reef in this area during early history of the islet.

Also on Jabor, but in a narrow section about a mile farther southwest, a trench dug across the land almost to low tide level illustrates that here, on the other hand, little or no beach sand development is represented (Fig. 15A). This section shows that above typical reef rock in the bottom is a 3-foot layer of brown, well cemented conglomerate, apparently formed under storm conditions during an early stage in the development of this islet. White, poorly consolidated but otherwise similar gravel above apparently had a similar origin at some later date. Thus, in this part of the islet there is no evidence of rocks having been formed by the normal beach accumulation of fine sediments.

Studies on Mejatto Islet illustrate variations during early stages of development in relative contributions of the two types of deposits (normal and storm) similar to those described from Jabor (Figs. 14, 15C-D). The transport of materials towards and into the lagoon is evident from a comparison (cf. Fig. 16) of aerial photographs made prior to OPHELIA (in 1944) and afterwards (in 1958).

Modifications of islet strata resulting from typhoon

A principal objective of the present study has been to determine and record the effects of Typhoon OPHELIA on the geomorphic and structural features of islets on Jaluit Atoll. This has been accomplished by examining in detail, measuring, and plotting in cross-section available data for two islets -- Jabor and Mejatto -- known to have been especially hard hit and awash during the storm. Effects of the typhoon on these islets include both accretion and removal of material and an attempt is made to indicate the distribution and extent of these changes.

Sedimentary deposits, adding to the bulk of Jabor and Mejatto Islets and attributed to Typhoon OPHELIA (possibly also, in part, to the storms of 1957) consist of very slightly weathered or unweathered gravels ranging

from pebble to boulder size with very little interstitial sand or other fine particles. They consist in part of material torn loose from the reef front.* Such fresh gravels are readily recognized by color, being uniformly white, in contrast to older gravels that are gray or brown either as a result of algal covering or of weathering in a soil zone. Imbrication is commonly developed among flat gravels, with surfaces dipping in the direction from which the storm waters advanced.

Based upon their geomorphic position, gravel accretions of the typhoon may be divided into three classes. These are (1) gravel tracts that locally form bars on the seaward parts of the reef, (2) shore ridges, referred to as ramparts by many geologists, and (3) gravel sheets or blanket deposits.

Gravel tracts were especially well developed on the reef flat seaward of Jabor Islet (Fig. 15A-B, Pl.I-a,-b), where for most of its length they formed a ridge 8 feet high and 45 to 60 feet wide; they were less well developed seaward of Mejatto Islet. In both places they contained abundant blocks and boulders from one to five feet in diameter, many of which were recently derived from the reef front as shown by their fresh, uneroded surfaces and by the types of coral represented. They had been transported landward as shown by sections across the ridge near Jabor where conspicuous imbrication of large slabs dipping seaward, constitutes the principal structure. At the time of examination, three months after Typhoon OPHELIA, gravel in these tracts had already migrated toward the islet a considerable distance, according to observations of Mackenzie and others who have been on the ground during that interval, and there seems little reason to doubt that normal wave processes will eventually carry them further back and add them to the seaward deposits of the islet.

Shore ridges, as exhibited on the seaward sides of Jabor and Mejatto Islets, are in all essential respects, except location, like the gravel ridges on the reef. They represent an ultimate in accumulation and piling up of coarse debris. They rise higher and contain larger boulders than other geomorphic forms on the islets and indicate the maximum storm concentration along the islet front. Structurally also they appear similar to the gravel ridges or the reef and probably are enlarged by material from these when landward migration has continued sufficiently.

The most significant additions, quantitatively, to the islets during Typhoon OPHELIA, are the blanket deposits of gravel, here termed gravel sheets. These extend as thin layers of white, little-weathered gravel across large parts of those islets that were inundated by storm waters and they appear to have been spread out and deposited in the manner of river flood or glacial outwash plains. Examples on Mejatto Islet (Fig. 16, 17) begin on the seaward side immediately lagoonward of the shore ridge or of scour channels and plunge holes as layers of loose gravel a few inches thick and in places they extend two-thirds or three-fourths of the distance across the islet. They end abruptly, forming a ledge or nearly vertical drop of two or three feet along a sinuous front.

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* This also is Banner's conclusion, see p. 76.

Texturally they are distinctive because of the absence of sand or other fine sediment as matrix. Structurally they form a single bed or layer, but commonly show imbrication of flat slabs within.

Gravel sheets spread over the islets contain particles that vary considerably in size from place to place as shown on Mejatto and Jabor but, in general, the particles in these sheets are considerably finer than gravels of the shore ridges and beach tracts. The gravel sheet appears to have been derived from at least three sources: (1) The outer reef area; (2) earlier shore ridges; and (3) reworking and redistribution of gravel of older sheets, with a winnowing away of soils and fine materials. It was not possible during the present study to determine the relative contributions from each of these sources. A significant observation, however, is that enough gravel was introduced from outside the islet in most parts of the sheet to raise appreciably the general island level in those places and to leave a new stratum of gravel as a record.

Although a considerable amount of sediment, nearly all coarse, was deposited on islets by the floodwaters developed during Typhoon OPHELIA, notable erosion also resulted from these waters. Evidence of such erosion is especially conspicuous in areas on the islets that apparently were occupied by relatively weak sediment adjacent to resistant surfaces. On both Jabor and Mejatto Islets, scour trenches several feet deep were cut into unconsolidated sand deposits landward from and parallel to beds of resistant beach rock that dip toward the sea (Fig. 17). On Mejatto many plunge holes were developed, one of them six feet deep, in weak deposits of sand to the lee of areas tightly bound by the root systems of trees (Fig. 17A-B). Thus, with the advance of water from seaward, a selective scouring developed in unprotected areas southwest of obstructions on the seaward sides of the islets.

Erosion also was considerable in areas bordering the lagoon shores of islets, especially between the margins of newly formed gravel sheets and resistant beach rock of the lagoon edge. In such areas water apparently concentrated in channels to scour out large plunge holes that have subsequently formed tidal pools (Fig. 15D).

A very large amount of fine sediment, especially of sand size, must have been removed from the islets of Jabor and Mejatto by flood waters of Typhoon OPHELIA. These fine sediments were winnowed out of the sandy gravel of the island and were largely stripped from former sand areas. At present the only significant sand areas exposed on these islets are in the bottoms and sides of deep scour channels and undercut areas around trees and beach rock. Some of the large amount of sand that apparently was once present, judging from remnants, now forms bars that extend out into the lagoon at various places; some of it constitutes submarine offshore bars (Fig. 14) formed by waves. The great bulk, however, presumably has been carried into the lagoon whose floor is now considered to have been raised appreciably.

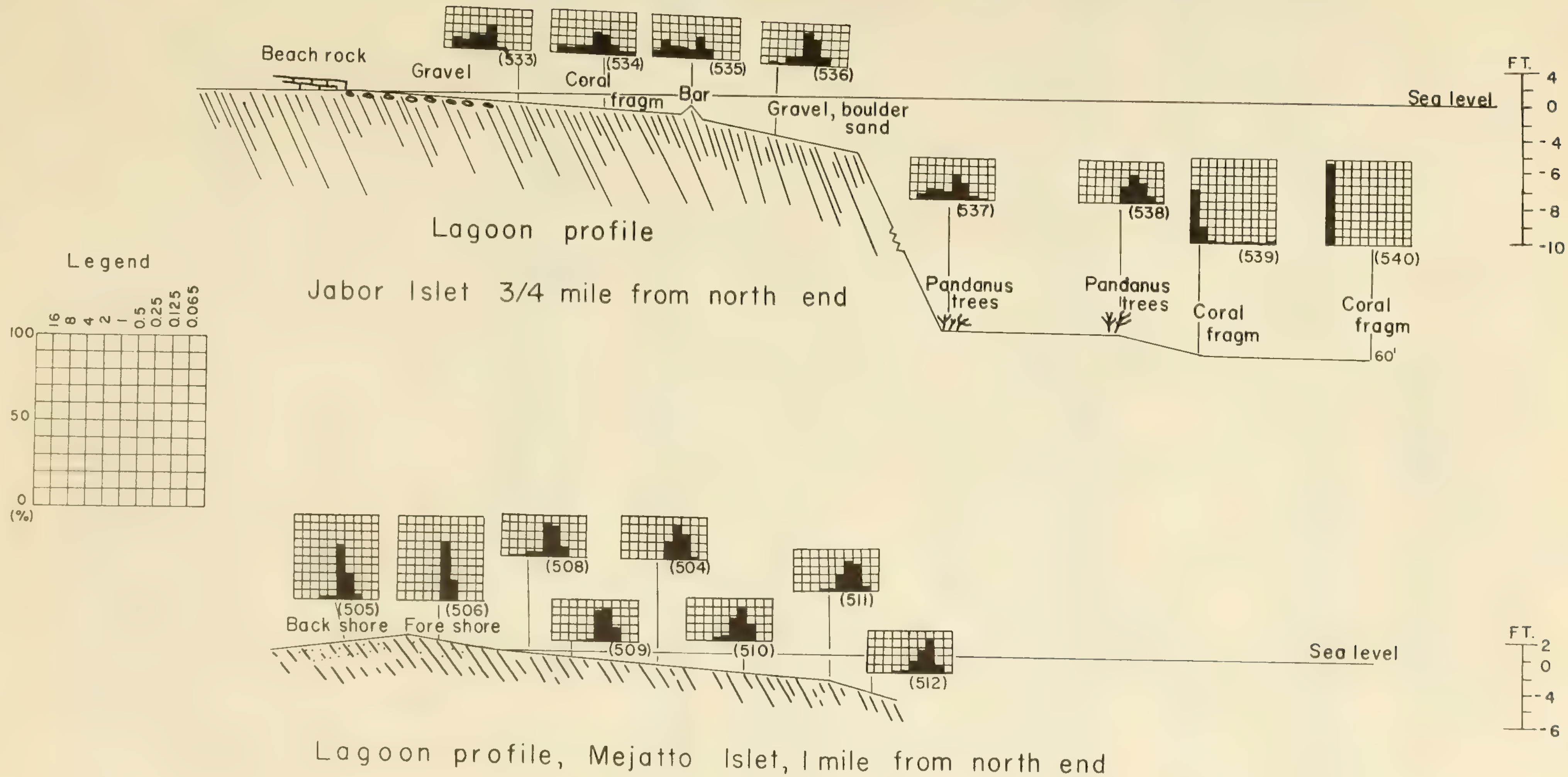
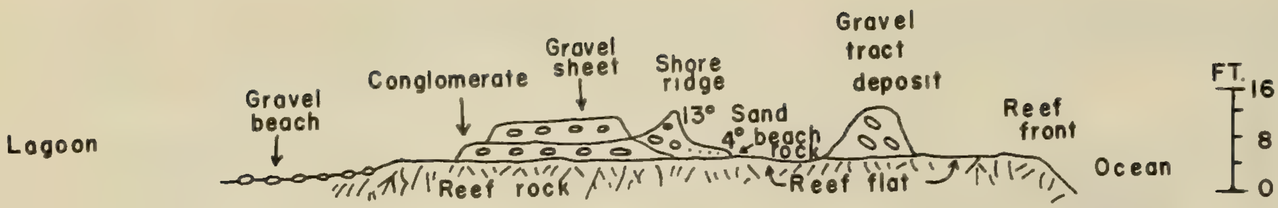
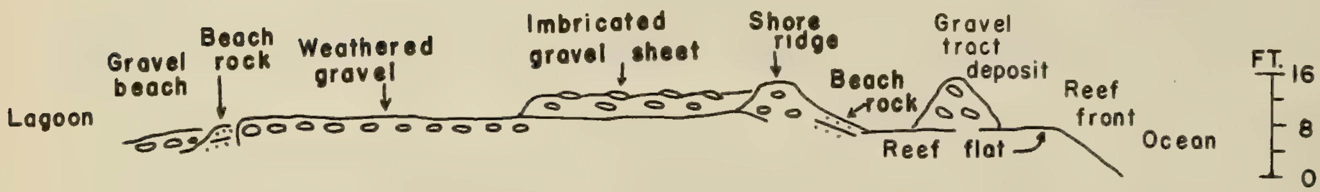

Beach rock
Gravel
(533)
Coral fragm
(534)
Bar
(535)
Gravel, boulder sand
(536)
Sea level
FT.
4
0
-4
-6
-8
-10
(537)
Pandanus trees
(538)
Pandanus trees
(539)
Coral fragm
(540)
Coral fragm
60'
Lagoon profile
Jabor Islet 3/4 mile from north end
Legend
16
8
4
2
1
0.5
0.25
0.125
0.065
100
50
0
(%)
(505)
Back shore
(506)
Fore shore
(508)
(504)
(509)
(510)
(511)
(512)
Sea level
FT.
2
0
-4
-6
Lagoon profile, Mejatto Islet, 1 mile from north end
0
100
200
FEET

FIGURE 14



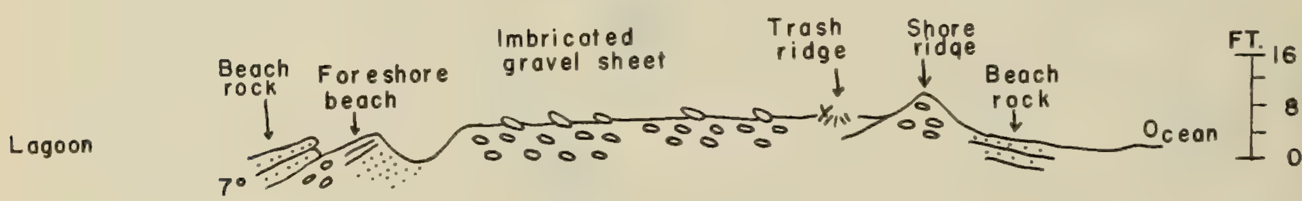
A. NW-SE Profile, Jaluit Islet

1 1/4 miles from north end (artificial trench)



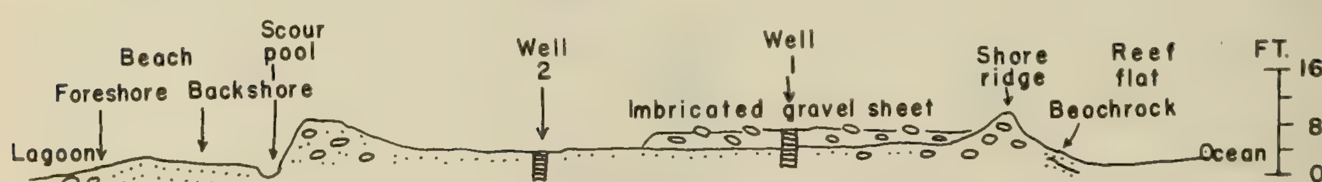
B. NW-SE Profile, Jaluit Islet

3/4 mile from north end



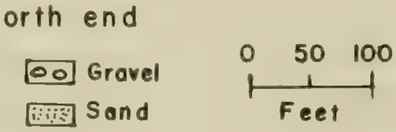
C. SW-NE Profile, Mejatto Islet

1 mile from north end



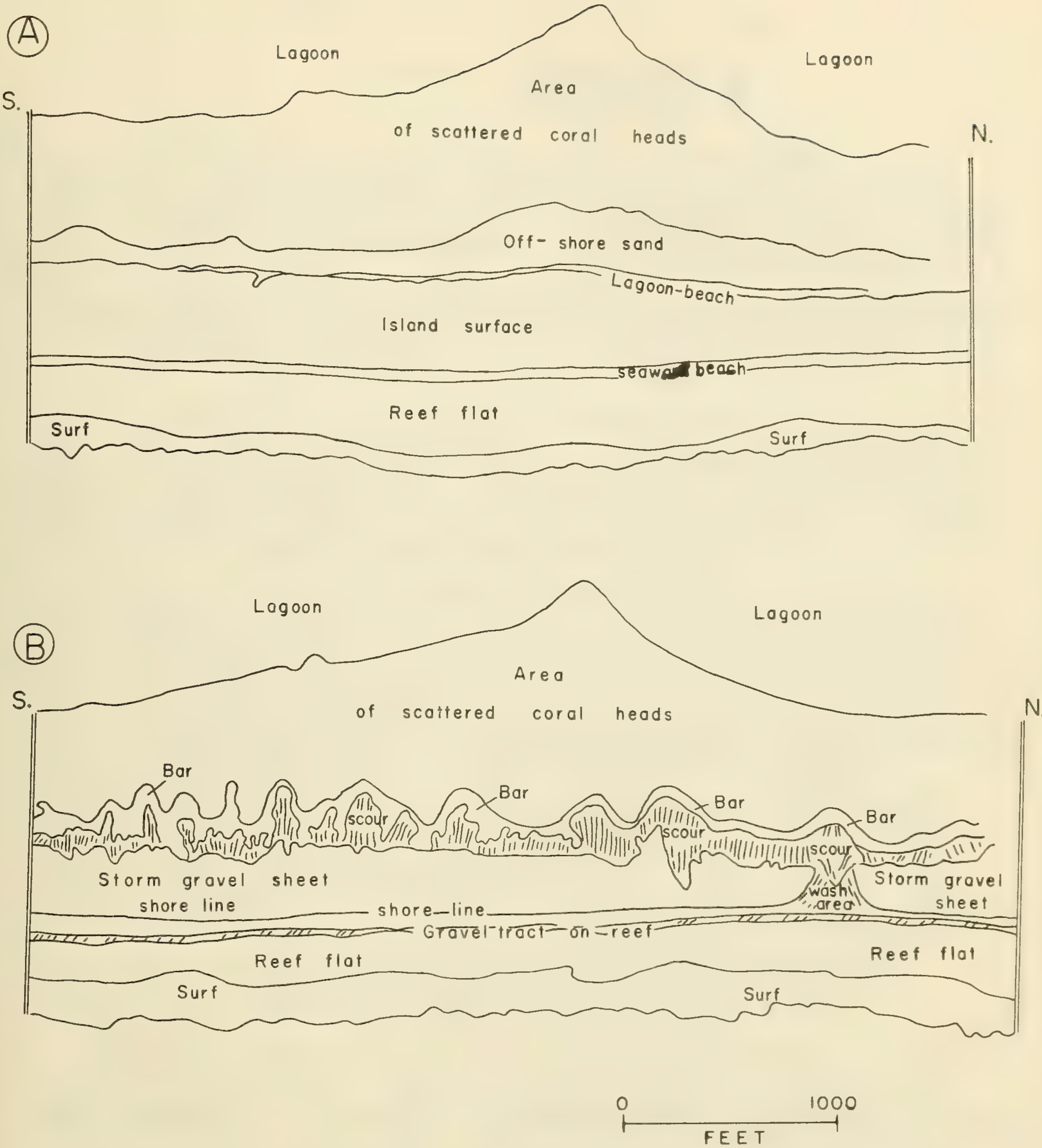
D. SW-NE Profile, Mejatto Islet

1/4 mile from north end



SECTIONS ACROSS JALUIT AND MEJATTO ISLETS

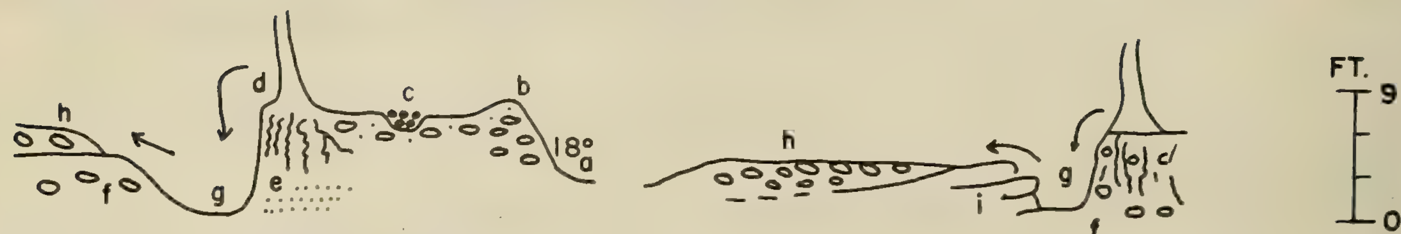
FIGURE 15



Section of Southern Mejatto A: 1944 B: 1958

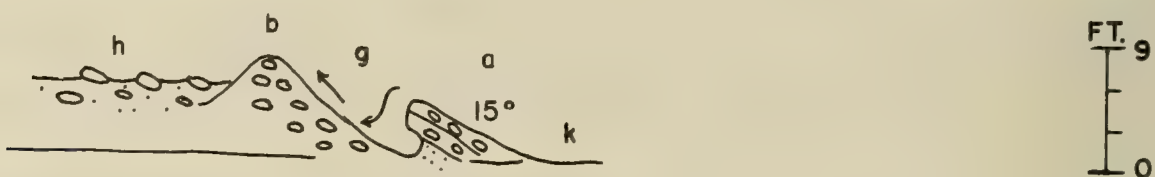
FIGURE 16

FIGURE 17

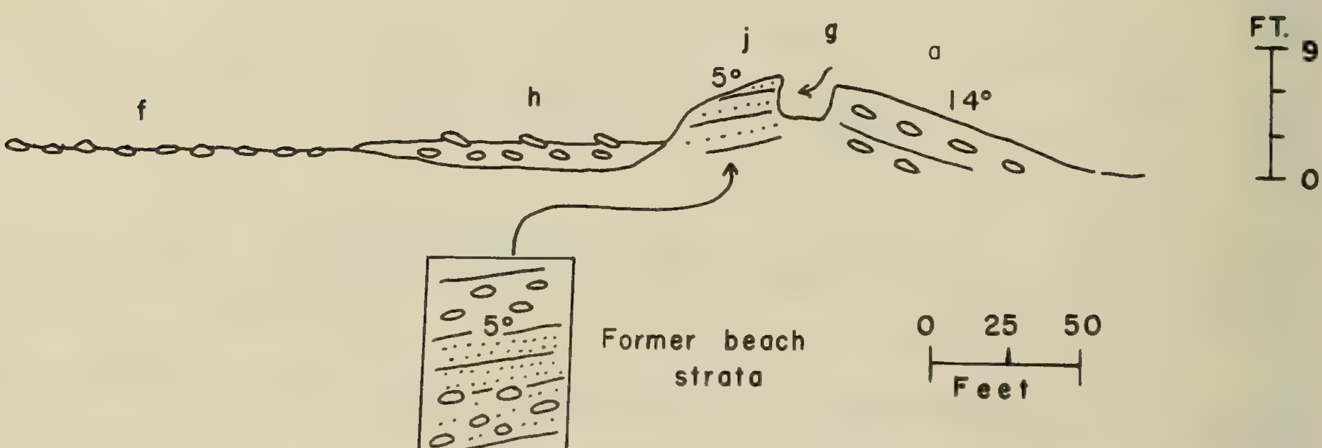


A. SW-NE Profile, Mejatto Islet
1 mile from north end

B. SW-NE Profile, Mejatto Islet
1 mile from north end



C. SW-NE Profile, Jaluit Islet
1/4 mile from north end



D. SW-NE Profile, Mejatto Islet
1 1/2 miles from north end

SCOUR CHANNELS AND GRAVEL DEPOSITS FORMED BY TYPHOON OPHELIA ON JALUIT AND MEJATTO ISLETS

a. Beach rock
b. Gravel shore ridge
c. Debris, mostly logs, from typhoon
d. Roots of coconut tree
e. Unconsolidated sand
f. Weathered gravel, unconsolidated
g. Scour pit or scour trench from typhoon
h. Gravel sheet from typhoon
i Beds of conglomerate
j Sandstone, former beach
k Reef flat
↘ Direction of water movement

V. REMOVAL OF FINE SEDIMENTS FROM ISLETS

Edwin D. McKee

Sand and soil are nearly absent on Jabor and Mejatto Islets, both of which were awash during Typhoon OPHELIA. That such sediments formerly constituted significant parts of the surfaces of these islets is indicated by the prevalence of sand and soil on other islets, e.g. Pinlep and Majurirek, which were not flooded, and on the unflooded northern end of Mejatto Islet. Not only has sand that presumably once formed beaches along these islets largely been removed, but also sand and soil appear to be thoroughly winnowed out from among the cobbles and pebbles that now form a gravel sheet across much of these islets.

The destination of fine materials removed from the islets by storm waves has been determined by investigations of two types. First, a study has been made of sediments from the lagoon shore outward to determine the present position of various size-grades of material. Second, a comparison has been made of offshore geomorphic features of 1944 with those of 1958 through a comparison of aerial photographs.

The lagoon area off Jabor Islet was selected for examination of bottom sediments because it represents a place in which storm intensity and islet flooding had reached a maximum. Analyses of samples at 100- to 200-foot intervals from the shore outward and from depths down to 60 feet were made (Fig. 14). These show only coral gravel from the shore line outward 180 feet, poorly sorted lime-sand between 180 and 1000 feet, and an accumulation of leaf-like and branch-like coral fragments (Montipora sp. and Acropora sp.) beyond 1000 feet. This distribution is attributed to Typhoon OPHELIA. The lagoon beach with its lack of sand is in contrast with lagoon beaches developed by normal wave and tidal action. Poor sorting of the offshore sands and a lack of progressive decrease in median size with depths and distance outward suggest rapid deposition with consequent mixing. In those respects they differ considerably from offshore sediments reported from Kapingamarangi Atoll formed under conditions of normal sedimentation(McKee, Chronic, and Leopold, 1959, figures 5, 7, 8, and 9).

Additional features of the lagoon floor off Jabor Islet attributed to Typhoon OPHELIA are an offshore sand bar or ridge, parallel to the shore at 400 feet out, and a large accumulation of Pandanus trees from the land that rest on the sand floor at the 50-foot level, immediately beyond a steep drop-off 600 feet from shore (Fig. 14).* Thus the storm has left a record offshore consisting of poorly sorted fine sediments and land-derived materials which, if buried and preserved, will appear very different from the normal offshore deposits.

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* See Banner's remarks, pp. 77-78.

Pinlep and Majurirek Islets, where the typhoon effects were great but where flooding of the land did not develop as on Jabor, were also studied from the standpoint of lagoon sediments. Relatively little fine sediment was removed from these islets. Nevertheless, the offshore sands are poorly sorted (figure 18) as on Jabor, and seem to indicate a considerable amount of mixing as far out as samples were taken, 600 to 700 feet, and at depths as great as 15 to 25 feet. In contrast, lagoon beaches on these islets were formed of sand, analyses of which show good to fair sorting similar to that of beaches developed under normal conditions of reworking by waves and tides.

Constituents of offshore sand in the Jaluit Lagoon are shown by sample counts to consist largely of broken and worn pieces of coral, although mollusk shell fragments are also very common in all size grades. The tests of foraminifers, relatively uniform in size, make up more than 50 percent of the particles in the coarse-grain size, but are scarce in other size grades. Other contributions, including sea urchin spines and sections of Halimeda, are quantitatively unimportant. Comparison of these sediments with those accumulated at Kapingamarangi Atoll in similar locations but under normal conditions of waves and currents, suggest that the proportionately smaller amount of foraminifera in the very near-shore waters and their correspondingly greater numbers far out from shore at Jaluit are direct results of redistribution by the typhoon (McKee, Chronic, and Leopold, 1959). The relatively larger amount of coral debris may also be a result.

Studies of bottom sediments on seaward sides of islets on Jaluit Atoll were attempted for comparative purposes. On Jabor and Mejatto Islets sand was absent, probably having been removed by the storm waters that swept from these reef flats entirely across the islets. On Pinlep and Majurirek Islets, where storm effects were less intense, fine sediment of the reef flat was poorly sorted and relatively coarse, median diameters being greater than sand size (figure 18). The sediment was composed largely of coral fragments, contained some broken mollusk shells and Halimeda segments, but no foraminifers. Apparently most of the fine sand, if formerly present, had been removed.

Sand beaches are at present non-existent along much of the lagoon side of Jabor and Mejatto Islets. Aerial photographs taken since Typhoon OPHELIA reveal that a considerable area formerly occupied by beaches on these islets is now scoured to reef rock surface and sand deposits currently form loops, or bars in the offshore waters, each bar appearing as a half circle, convex outward. This pattern is especially well developed and forms a conspicuous feature along the middle part of Mejatto Islet (Fig. 16). Gentle lagoonward slopes and steeper shoreward sides on these bars, as seen in the photographs, are believed to result from gradual reworking of the sand masses by incoming waves off the lagoon.

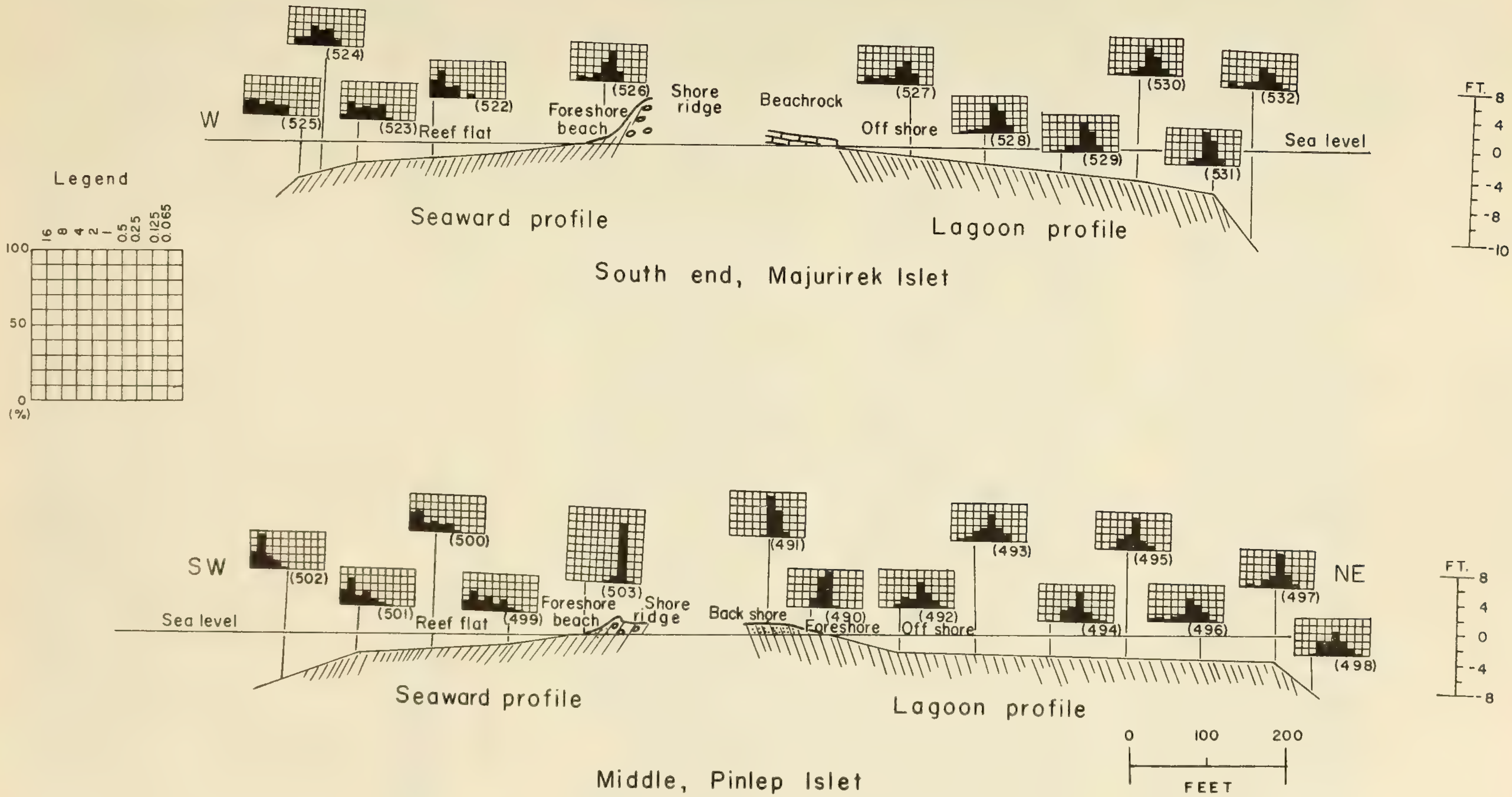
Legend
16 8 4 2 1 0.5 0.25 0.125 0.065
100
50
0
(%)
W
(524)
(525)
(523)
Reef flat
(522)
(526)
Foreshore beach
Shore ridge
Beachrock
(527)
Off shore
(528)
(529)
(530)
(531)
(532)
Sea level
Seaward profile
Lagoon profile
FT.
8
4
0
-4
-8
-10
South end, Majurirek Islet
SW
(502)
(501)
(500)
Reef flat
(499)
(503)
Foreshore beach
Shore ridge
Sea level
(491)
Back shore
(490)
Foreshore
(492)
Off shore
(493)
(494)
(495)
(496)
(497)
NE
(498)
Seaward profile
Lagoon profile
0
100
200
FEET
FT.
8
4
0
-4
-8
Middle, Pinlep Islet

FIGURE 18

VI. GROUND WATER

Edwin D. McKee

Although no studies of ground water had been made on the islets of Jaluit Atoll prior to the coming of Typhoon OPHELIA, dug wells have for many years furnished potable water, so fresh water lenses may be assumed to have existed on all but the very small islets. The quality of this water probably was similar, in general, to that reported from fresh water lenses on other Pacific limestone islands. Storm waves of the typhoon, however, submerged many of the islets, so their supply of ground water was locally contaminated and its composition greatly altered by mixing with sea water.

Samples of ground water were collected for analysis in May, 1958, about four months after the storm. These samples were obtained from four wells in existence prior to the typhoon, three wells dug at the time of sampling, one scour pool cut by the typhoon, and one mangrove pond (for location of wells, see Figs. 6, 8, 11, 12, 13). The three test wells and one of the original wells were on islets known to have been covered by a sheet of water during the typhoon (Jabor and Mejatto); the other three old wells were on islets not inundated (Pinlep, Majurirek, Kinajon) and their waters apparently were relatively little changed as a result of the storm.

Temperature and pH readings were taken at each of the wells examined (Table III). Temperatures ranged from 82° F. to 87° F. These were read near the middle of the day and probably are relatively high because all of the wells were in the open, unprotected from the sun, as a result of typhoon destruction of surrounding trees. Well waters ranged from about pH 6.0 to pH 7.0, all of the higher figures representing wells on islets known to have been inundated by typhoon-driven sea water.

TABLE III.--Readings of pH and temperature for well water

Well description	pH	Temperature*
Majurirek	6.0	86
Pinlep	6.5	83
Mejatto well #1	7.0	85
Mejatto well #2	7.0	87
Jabor well #2	7.0	82

* degrees Fahrenheit

Hardness of water (Table IV) in the three samples from islets not inundated by storm waves is less than 500 parts per million; in all others it is greater than 1200 ppm, apparently the result of contamination by sea water. Thus, low calcium and low magnesium in well waters of Pinlep, Majurirek and Kinajon islets probably represent amounts normal for fresh water on these islets; water of similar composition is reported from

fresh water lenses in the northern Marshall Islands (Arnow, 1954, p.7) and on Kapingamarangi Atoll (McKee, 1958, p. 267). The amount of calcium and magnesium in such waters, higher than in average fresh water streams and lakes, results from solution of limestone and lime sand of the islets.

Well water from Jabor and Mejatto Islets (Table IV) which were covered by sea water during the typhoon are much higher in both calcium (over 200 ppm) and magnesium (over 170 ppm) than water from the islets cited above that were not inundated. Furthermore, the amount of magnesium in the Jabor-Mejatto samples is essentially equal to or greater than the amount of calcium, a result of contamination, since normal sea water has proportionately more magnesium than calcium, whereas most fresh waters are the reverse.

The extent of contamination by sea water is illustrated by analyses of sulfate (SO_4) and chloride (Cl) for well water from Jabor and Mejatto Islets (Table IV). Both of these islets were covered by ocean water during the typhoon, but apparently the lens on Mejatto with a combined sulfate and chloride content ranging from 10,000 to 15,000 ppm was contaminated more than that on Jabor where it ranges from 4,000 to 5,000 ppm. It is instructive to compare these figures with the 250 ppm sulfate and 250 ppm chloride recommended by the U. S. Public Health Service as the upper limit for water used in normal domestic consumption.

A summary of available data on the ground water resources of Jaluit Atoll after Typhoon OPHELIA is as follows. The fresh water lenses on those islets not covered by storm waters appear to be normal for Pacific atolls and probably were little or not affected by the typhoon. The fresh water lens on Jabor and that on Mejatto, judged by samples from two wells on each, show a sulfate-chloride content far too high for drinking purposes and will require a considerable period of dilution by rainwater to again become potable. How long a period of "freshening" will be needed with present annual precipitation of about 200 inches, is not known, but samples from the four wells in question, collected and analyzed periodically during the coming year should give significant information.

TABLE IV.—Analyses of water samples from original dug wells and test wells and comparative data for a mangrove pool and for normal sea water. (Analyses by U. S. Geological Survey)

LOCATION OF WELL	Chemical Components (ppm)						Physical characteristics		
	Ca	Mg	Na	K	SO_4	Cl	Hardness (ppm)	% Sodium	Sp.Gr.
Majurirek, 190 feet from lagoon beach crest W. end of island center.	102	17	138	11	45	238	324	47	1.000
Pinlep, 190' from lagoon beach crest.	53	8.8	62	5.8	26	62	168	43	1.000
Kinajon, 130' from low water, 99' from ridge on SW islet.	142	27	316	27	102	570	466	58	1.000
Mejatto, well #1, 174' from seaward gravel ridge.	285	529	4900	214	1370	8700	2890	73	1.011
Mejatto, well #2, 301' from lagoon beach crest.	362	888	7550	252	1910	13000	4550	77	1.017
Jabor, well #1, 130' from lagoon beach crest.	223	242	1990	84	535	3390	1550	72	1.004
Jabor, well #2, 265' from lagoon beach crest.	207	174	1500	84	473	2890	1230	71	1.003
Mejatto, water from scour pool on lagoon side of islet behind beach crest.	159	415	3570	147	1010	5950	2100	77	1.008
Majurirek, water from mangrove pond.	376	1090	8700	376	2300	14900	5420	76	1.020
Normal seawater.	400	1270	10560	380	2650	18980	6215	79	

VII. SOILS

F. R. Fosberg

Following Stone (1951, 1953) and Fosberg (1954), the principal soils on Jaluit Atoll fall into five categories: (1) Shioya Series, (2) Arno Atoll Series, (3) Jemo Series, (4) mangrove peat, and (5) stony and very stony complex.

The Shioya soils are gray-brown slightly altered lime-sands with varying amounts of gravel, the A-horizon, colored slightly by humus, varying in thickness, depending on the time elapsed since the last disturbance and type of vegetation. The B-horizon is lacking and the C-horizon is lime sand, not much altered, scarcely distinguishable from beach materials. This soil tends to be peripheral on the islets but may also be found in the interiors.

The Arno Atoll soils have a black or very dark gray A-horizon from 1 to several dm. in thickness. The organic content is high. The B-horizon, again, is lacking, and the C-horizon is similar to that of the Shioya with a gradual transition from the A. This series is found generally in the interiors of islets but may extend almost or quite to the lagoon beach. This soil is unquestionably much older than the Shioya.

The Jemo series (Fosberg 1954) has an A-horizon of pure humus varying in thickness up to a dm. or rarely more. Usually it has a consolidated B-horizon of highly phosphatic material of varying thickness. This lies on a C-horizon similar to that of the two foregoing series. Three areas of this series were found during the present survey, none of them typical. On Lijeron Islet under the Pisonia trees the A-horizon is well developed but somewhat mixed with lime-sand. The B-horizon is only slightly and very locally developed. On Imroj Islet the A-horizon is lacking and the B is eroded and cracked into a boulder-field (Pl. VIII-d). It is on the extreme northwest end of the islet, just south of a small mangrove depression. On Kinajon Islet the A-horizon is lacking in parts, present but rather thin elsewhere. Here the Jemo series occupies slightly high ground inside a roughly crescent-shaped group of mangrove depressions near the outer part of the islet. These soils are of great importance because of their phosphatic B-horizons.

The mangrove peats are soft to firm, red to black, purely organic accumulations found especially around mangrove depressions.

The stony and very stony complex is the undifferentiated gravel of varied sizes found especially in peripheral ridges (often termed boulder ridges or boulder ramparts), sometimes in wider areas. It may be very loose and porous, or may contain fine material, often highly organic, between the stones.

Time was not available for mapping these types, nor for mapping the areas of them that were either buried or stripped away by the typhoon. This damage was not very significant on those islets or parts of islets which were not swept over by waves, especially the islets on the south

and west reefs, and presumably in the extreme north of the atoll. On the east reef islets, judging from work on the ground on four islets and aerial inspection of the rest, considerable areas of stony and very stony complex were stripped off, usually exposing either more of the same or beds of poorly consolidated conglomerate (Pls. II-a, V-b). Stripping was rather general along the seaward sides of most of the islets. This rocky material, probably including some freshly thrown up from outside the reef, was mostly spread inland, covering an estimated third or fourth of the total land area of these islets with a gravel sheet that will have to be classified with the stony and very stony complex (Pls. III, VII-b, IX-d, X-b). The buried soils here, at least where examined, were largely Arno Atoll, some Shioya. Lagoonward from the usually abrupt edges of this gravel sheet (Pl. III-a,-b) the Arno Atoll and Shioya soils are in places covered by a few cm. of lime-sand. On these same islets small areas, totaling a considerable amount, were scoured by the waves, removing the A- and often part of the C-horizon.

It is hard to estimate the agricultural significance of this destruction of soils. Unquestionably, where the surface soils have been removed there is a great decrease in fertility. To replace the humus lost from both the Arno Atoll and stony and very stony areas would require fallowing under vegetation for a long time. Even to bring about the slight humus accumulation characteristic of the Shioya soils will require a considerable fallow period. Analyses of similar soils from other atolls show that a large part of the mineral nutrients is concentrated in the more highly organic layers. Cessation of the common Marshallese practice of burning trash and brush would greatly hasten the needed humus accumulation.

The areas stripped down to consolidated material will certainly not be of any immediate agricultural use. Any vegetation that can be encouraged to grow on these areas will be of benefit, both in helping to disintegrate the rock and in accumulating wind-blown material and humus.

The areas covered by fresh gravel sheets would not seem to be very promising for any sort of agriculture. However, if the practice of planting coconuts in 3' x 3' x 3' pits is followed it is probable that in many places these pits may extend down through the gravel layer into the buried Arno Atoll or Shioya soils. The overlying material would then be of no consequence except to make digging more laborious.

The mangrove peat was not noticeably influenced by the typhoon except that in several places small areas were covered by deposits of wave-carried gravel (Pl. III-c,-d). Usually great quantities of vegetable trash were dumped into the mangrove depressions by the waves (Pl. V-c). This will, of course, eventually add to the peat.

An interesting feature was the buried A-horizon, at somewhat less than 1 m. depth, encountered in a well dug under Dr. McKee's direction near the center of the northwest end of Mejatto Islet. This apparently indicates the burial, at some earlier time, of an Arno Atoll soil, perhaps by a typhoon. The overlying material is a gravel similar to that of the gravel sheets laid down by the waves of Typhoon OPHELIA.

Another item of interest is the abundance of pumice fragments scattered inland wherever the land was inundated. Some of these were undoubtedly washed out of preexisting gravel ridges and soil layers, but much of the pumice probably came from the beaches, where much has accumulated, floated from across the sea, especially after the eruption in 1952 of San Benedicto Volcano, off the Mexican Coast (Richards 1958). That this pumice contributes to the fertility of the soil is indicated by the proliferation of roots tightly surrounding particles of pumice buried in atoll soils, observed both on this survey and in the northern Marshalls. Pounded pumice is used to fertilize gardens and taro pits in various atoll groups.

The Germans and Japanese had brought large quantities of volcanic soil from Ponape and spread it over certain areas on Jabor. One of these patches has now settled so that it is covered by salt water at the highest tides. Although all of the imported soil was inundated by sea water during the typhoon, it seems mostly still there and is now supporting a rank growth of weeds.

The overall consequences of the typhoon are unquestionably a loss in productive soils. However, this may be mitigated to some extent if the trash (Pl. VI-d) strewn over the islets by the typhoon and that accumulated under normal circumstances are allowed to rot, rather than being burned as has already started in several places.

VIII. FLORA AND VEGETATION

F. R. Fosberg

The indigenous flora of Jaluit Atoll is an enriched strand flora, typical of that of wetter atolls in the west central Pacific. In addition to most of the ordinary widely distributed strictly strand species that are to be expected in tropical maritime situations, wet sheltered forest sites have permitted the establishment of certain more mesophytic species not ordinarily found on strands. Peperomia ponapensis, Procris pedunculata, and Vittaria elongata are examples of these. The Marshallese made their contribution to the flora by bringing in such economic plants as the breadfruit, the taros, at least some kinds of pandanus, the coconut and others as well as a few weeds. Since the arrival of the first Europeans many weeds, some new food plants, and an array of ornamentals have been introduced, either deliberately or accidentally. The only peculiarity of the Jaluit flora is the presence of an unusually large number of these exotics resulting from the fact that the atoll was the site of the German and Japanese administrations and of a short-lived agricultural experiment station started by the present administration. A list of the known flora is to be published in another number of the Atoll Research Bulletin (see also Appendix I).

The islets of Jaluit Atoll, before the typhoon, had mostly been planted to coconuts and breadfruit. Except for the plantations only a few important vegetation types were present, and these in small areas. They were Pemphis forest or thicket, Pisonia forest, mangrove depressions, taro pits, and fringes of dense scrub along the windward sides of some islets, outside the plantations. A few open grassy areas represented abandoned gardens, as on Kinajon Islet and possibly Pinlep Islet.

The plantations (Pl. V-a,-b,-c) were either coconut, coconut and breadfruit, or rarely just breadfruit. The trees were from 15 to 25, rarely 30 m. tall, closely spaced, usually less than 6 m. apart. A scattered understory of Pandanus (Pl. V-c) up to 5 to 8 m. tall occurred in most parts, most of the trees being of varieties yielding edible fruits. Other small trees and shrubs, especially Morinda and Allophylus, were present but irregularly distributed, depending on the local productivity of the land and on the diligence of the plantation owners in clearing out the undergrowth. A ground cover of grasses, sedges, Wedelia, ferns, and other herbs was general. Epiphytic mosses and ferns were common, especially in denser parts of the plantations.

Around the edges of the plantations, especially on the gravel ridges on the windward sides of the islets, was usually a narrow zone of scrub composed of Scaevola sericea, Tournefortia argentea, Guettarda speciosa, Terminalia samoensis, and other woody species. In some very rocky areas, both in the scrub and in the coconut groves, Fleurya ruderalis, Boerhavia tetrandra, and Euphorbia chamissonis were common, forming a scattered ground layer. In a few spots in the coconut plantations near the windward side were groups of large trees of Barringtonia asiatica. Intsia bijuga and Ochrosia oppositifolia were also present in small groups.

Around villages, isolated dwellings, and grave yards were a few species of ornamentals, planted as scattered trees or bushes, hedges or borders, or in small gardens. Most of them produced flowers used for leis or garlands. Especially common were Pseuderanthemum, Plumeria, Crinum, Acalypha, Zephyranthes, Polyscias, Mirabilis, Catharanthus, Asclepias, Gomphrena, and Ocimum. Such food plants as Pandanus (Pl. V-a), bananas, papayas, and squashes, also were very common in the vicinity of dwellings.

On Jabor, the northern extremity of Jaluit Islet, where both the Germans and the Japanese had their headquarters, a great many cultivated exotic species were planted. Volcanic soil was brought from Ponape and spread in certain spots, making possible gardens with many species not commonly found cultivated on atolls. Certain weeds also became established in Jabor. Several years ago the U. S. Administration started an agricultural experiment station on Jabor, and more plants were brought in. Over a hundred species of cultivated plants and several weeds not normally found on atolls in this part of the world have been reported from Jaluit by German, Japanese, and later writers. Many of these have not persisted, but up to the time of Typhoon OPHELIA a substantial number were reported by Boyd Mackenzie to be growing on Jabor and some had been carried to other islets of the atoll.

In certain places, either interior depressions or marginal places where gravel ridges have cut off areas of reef flat, the water table reaches the surface of the ground. Here coconuts do not thrive well and other vegetation is found. On Pinlep two such interior depressions have been converted to taro pits where the giant taro, Cyrtosperma, is the principal vegetation, along with several weeds characteristic of such habitats. These are, especially, Echinochloa crus-galli, Cyperus odoratus, and Eleocharis geniculata. There may have been others before the typhoon. Other such depressions have mangrove vegetation of one sort or another. Most of the depressions studied have essentially a pure stand of Bruguiera gymnorhiza or Bruguiera with some Pemphis acidula. One had Lumnitzera littorea. Another had Bruguiera with a dense understory of Hibiscus tiliaceus. Still another had Hibiscus only.

Along both seaward and lagoon shores are areas of rock flats of limestone conglomerate with little or no soil. Some such areas were bare or almost so. Others were covered by thickets or scrub forests of Pemphis acidula. One area of rock flat on the lagoon shore near Sydneytown had, in 1946, a sparse stand of a mangrove, Sonneratia alba, almost the easternmost known occurrence of this species.

On several tiny islets coconuts have never been planted in large numbers. Two of these, Ribon and Lijeron, have been examined briefly. The vegetation was largely Pisonia grandis, with Tournefortia, Guettarda, Intsia, and Terminalia samoensis around the shore ridges and Pemphis on rock flats In the interior of Ribon is an open area dominated by Asplenium nidus. Lijeron is the home of large numbers of sea birds, some of which nest in the trees.

The very small islets, though less disturbed, had a very restricted flora, as has been observed elsewhere on atolls (cf. Kapingamarangi, acc.

Niering, 1956). Of the larger islets the broad ones tend to have a larger flora than the narrow ones.

The effects of Typhoon OPHELIA, even on the same vegetation type, or on the same plant, were by no means identical in all localities and parts of the atoll. In general, the islets on the east side of the atoll suffered much more damage to their vegetation than those on north, south, and west. Also, as might have been anticipated, narrow islets or parts of islets were far more affected than broad parts. This was well illustrated on Jaluit Islet, where the narrow parts south of Jabor were in places completely stripped of vegetation (Pl. V-b). Also on Jaluit Islet the difference in damage depending on orientation of the islet is well shown. At the southeast corner of this islet (see Fig. 1) the part running north suffered very severe loss of coconut trees, this continuing southward to the point. On the leg of the islet running westward from the southeast point the damage was conspicuously less, the difference at the time of examination being between a barren expanse of coral with scattered trees and a solidly green islet. The islets along the south and west sides and around the north loop of the reef were generally green, while along the east side only the wider islets were green. This seems well correlated with the exposure of the eastern side of the atoll to a combination of strong winds and great waves which swept over the narrower islets and parts of islets. Some of the broader islets here were only partly inundated, while on the other sides of the atoll most islets escaped serious flooding by the salt water.

This combined action of wind and large waves had several effects on vegetation. Many trees were uprooted, either completely so (Pl. VI-a) and sometimes swept away, or partly so (Pl. VI-b) and remaining in place and frequently still alive. Some were snapped off (Pl. V-d). Branches were broken or torn off of most of those that remained standing (Pl.VI-c). Some exotic plants were killed or their above ground parts killed by salt. In places large scale burial of plants by gravel occurred (Pl.III-a, VII-b). Elsewhere the soil with its vegetation was scoured away (Pl.V-b). Many tree trunks were seen in the lagoon on the shallower slopes along the east side. Masses of vegetable debris were strewn at random on areas that were inundated (Pl.VI-d). Some of this seemed to have washed around and become very worn and battered before it was finally stranded. Enormous amounts of such debris were washed into some of the mangrove depressions (Pl.V-c). It was impressive that not only trees but even shrubs and coconut seedlings were knocked down or dismembered in these areas. However, no particular evidence of abrasion of bark by wind- or water-driven sand and gravel was seen. Defoliation, according to reports, was at least in places complete. Root systems were extensively exposed (Pl.II-c, -d, VII-a).

On parts of the wider islets of the east reef and on the islets on the other sides most or all of the damage to vegetation was by wind. Here the ground vegetation was little hurt. The trees and larger shrubs, however, were seriously damaged, locally almost all trees being uprooted or broken, usually a substantial proportion even in the less affected areas. In some places, as on Majurirek (Elizabeth) and Imroj, trees had fallen in at least three main directions (Pl.VII-c). More usually they were predominantly pointing in one direction. The direction of fall of the

trees, and its significance in terms of the storm, have been discussed above by Blumenstock and Wiens. Particular mention may be made of mangrove swamps and Pemphis thickets. Although the trees in these were in places uprooted, more often they were still standing but with their upper parts or branches dead (Pl.IV-d, VIII-c). A significant fact emerging from the observations on these islets that were not covered by salt water is that very serious damage to vegetation may result from wind alone (Pl.VII-d, VIII-a,-b).

Impressions gained of the comparative resistance to wind of different tree species are not very clear, as conditions varied so much locally. No kind completely escaped uprooting and breaking, but Pemphis, Cordia, Calophyllum, and Casuarina* perhaps stood up best, except for Bruguiera, which occurred in dense stands in low spots, where there was some protection. Pandanus (Pl.VII-d, X-c), breadfruit, and Terminalia catappa perhaps fared worst. Very few breadfruit trees with trunks 30 cm. or more in diameter remain standing, and the smaller ones which do remain have most of their branches torn off (Pl.VI-a, VIII-a,-b). Where inundated by salt water, breadfruit trees were killed or almost so. Of the larger shrubs Terminalia samoensis fared by far the best, suffering little damage. Small Pemphis bushes in some places escaped completely; others were snapped off (Pl.IX-a). The reactions of individual species are discussed in detail later on.

Smaller plants suffered perhaps less than others on the islets that were not inundated, but were enormously reduced in numbers on the ones swept by waves.

Recovery was well under way at the time of the survey, little over 3½ months after the typhoon. Most of the dismembered and defoliated trees were putting out an abundance of leafy sprouts (Pl.VIII-b,-c). This was not true of Pandanus, which was scarcely sprouting at all (Pl.VII-d). In the badly hit areas of the east reef most of the breadfruit trees were either dead or very slow in showing signs of recovery, possibly because of the salt water. Elsewhere they were sprouting actively. Many of the trees of all kinds that were completely down but had some roots still in the ground were still growing, some even flowering. Abundant seedlings were seen of Tournefortia, Scaevola, Guettarda, Morinda, and, very locally, Barringtonia, and Pandanus. Many of the herbaceous plants had come up from seed after the typhoon in great profusion in favorable habitats, some of them doubtless greatly increasing their numbers as a result of the thinning of the forest and the consequent lessened shade.

Recovery of individual species is discussed below. In general, native atoll plants and those long cultivated on atolls show active recuperative powers. Some of the planted species came back well enough. Others were doubtless lost. It is difficult to say what, if any, species were completely eliminated, as only a part of the atoll was examined. In addition to such planted things as several palms, two native mangroves, Sonneratia alba and Lumnitzera littorea, may have disappeared. They were

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* But see Wiens, p. 27.--F.R.F.

known on Jaluit Islet only, from one small colony each, and these places were examined without finding a trace of the plants. Of course they may still exist on other islets which have not been explored botanically.

Native agriculture and subsistence plants were badly hit, especially Pandanus (Pl. VII-d), breadfruit (Pl. VI-a, VIII-a, -b), and coconut (Pl. IX-c, -d), but no other food plants of consequence were more than temporarily damaged. Banana shoots and papaya seedlings were coming up in abundance. Squash were growing well. The taro pits were not seriously hurt (Pl. IX-b). These matters will be considered more in detail in the chapter on economic consequences.

IX. TYPHOON EFFECTS ON INDIVIDUAL SPECIES OF PLANTS

F. R. Fosberg

Observations were made on the effects of the typhoon on many individual species and their recovery. These are indicated in the following systematic list of species. The list includes all plants which were known or thought to be present on the atoll in 1946 or thereafter. Various species reported earlier but of which there are no recent records are omitted. Information has been supplied by Prof. Harold St. John and by Boyd Mackenzie, as well as taken from records gathered by the writer on a visit in 1946 and in the present survey. Names have been adjusted to correspond with those considered correct at the present time.

Asplenium nidus--Very frequent locally, terrestrial and epiphytic. Reduced in numbers as trees on which it was growing were swept away or as ground was covered by gravel, but still very common except where islets were seriously swept by waves.

Nephrolepis acutifolia--Common locally, epiphytic, especially in and around mangrove depressions. Reduced in numbers where trees on which it was growing were swept away and individual clumps killed or seriously injured by salt or wind, but generally recovering, still common in protected places.

Nephrolepis hirsutula--Common locally. No injury noted but doubtless reduced or eliminated where islets were seriously swept by salt water.

Polypodium scolopendria--Generally very common, terrestrial and on bases and trunks of trees; still so except where islets were swept by waves. Buried by gravel in places, but otherwise no injury noted; doubtless reduced in numbers where host trees were swept away.

Pteris tripartita--Occasional and very local in protected places; terrestrial. No injury noted but doubtless reduced in numbers by destruction of habitats.

Vittaria elongata--Rare, epiphytic. No injury noted except that some clumps may have suffered from exposure to sun or salt.

Cycas circinalis--Planted in Jabor only, rare. Leaves seriously battered, one plant, at least, uprooted.

Pandanus tectorius--One of the commonest trees generally, forming part of the vegetation on the seaward margins of plantations and the principal component of the understory. Trees generally very seriously battered, some uprooted, many more broken off between stilt roots and first branches, or with most of the branches broken off. Branches either broken in leafless part or torn from trunk. Sometimes a few tufts of frayed green leaves left

on trees, especially on those in more sheltered places. Even the trees otherwise in fair condition in least affected areas had leaves broken. No sprouting seen where breaks occurred below the leafy portions of branches or in trunks. The few sprouts noted were from the soft leafy parts of branches. Apparently the lower parts of branches, trunks, or roots have no capacity for sprouting. Young plants below 1.5 m. tall on the areas not swept by waves not particularly injured.

Thalassia hemprichii--In elongate patches on lagoon bottom in about 1 m. of water. No effects noted.

Cenchrus echinatus--Common locally. Absent from many places swept bare by salt water in situation where it would be expected to be abundant.

Cynodon dactylon--Scarcely seen, not known if it was common or not before typhoon; no obvious effects seen.

Digitaria pruriens var. _microbachne_--Widely distributed but local, not abundant. No effects noted, but some habitats undoubtedly rendered less favorable by removal of soil and flooding by salt water.

Echinochloa crus-galli--This species seen only in taro pits, where it forms large masses. No effect noted.

Eleusine indica--Very common. No obvious effects; but doubtless some habitats made less favorable and others more favorable, resulting in elimination where soil was removed or buried and greater abundance where trees were thinned and soil only moderately disturbed.

Eragrostis amabilis--Very common. No effects noted that might not have resulted from mere dry weather.

Lepturus repens--Very general, locally abundant. In places undoubtedly buried by gravel sheets; in many places removed by wave erosion; otherwise no effects noted. New open habitats will doubtless result in increase of this species in the near future.

Paspalum conjugatum--Only seen on Pinlep Islet, where it was very common. No effects noted, but thinning out of coconuts may well encourage this species, which was luxuriant in areas on Pinlep where many trees were knocked down.

Paspalum distichum--Found in brackish depressions. No effects noted, but scour pits may become habitats for this species.

Sorghum bicolor--Very rare, on Jabor only. No effects noted, plant very rarely persisting.

Thuarea involuta--Abundant, generally distributed. Undoubtedly buried in large areas covered by gravel sheet and removed in seriously eroded areas. Otherwise no effects noted except some browning of leaves, possibly by salt water.

Cyperus compressus--Local, in Jabor only. Inundated; no effects noted. These plants possibly grew from seeds since the typhoon.

Cyperus javanicus--Local, in low or wet places. No effects noted, but possibly some habitats buried by gravel or eroded away. Scour pits and channels may eventually become new habitats for this species.

Cyperus kyllingia--Occasional, only seen on Jabor. No effects noted except some browning of leaves and dwarfing of plants in areas flooded by salt water.

Cyperus odoratus--Seen only in taro pits. No effects noted.

Cyperus rotundus--Local, in Jabor village only. No effects noted except that only young shoots were seen. The tubers undoubtedly survived the inundation by salt water.

Eleocharis geniculata--Seen only on mud in taro pits. No effects noted.

Fimbristylis cymosa--Very general, especially in open places, locally abundant. Some stands of this species doubtless buried by gravel sheets, others eroded away by waves; gravel sheets doubtless will afford extensive new habitats. No effects noted in areas not affected by waves.

Cocos nucifera--Planted over entire atoll (Pl. IV-a,-b,-c). These trees showed the most conspicuous damage of all, because of their size and abundance. Thousands of trees were either uprooted or snapped off part way up the trunk (Pls.II-c,-d,V-d,VI-a,-b,-c,VII, VIII-a,IX-c,-d,X-a). On the islets along the east reef of the atoll the majority of coconut trees are down; on some islets almost all. On the south reef, west reef, and at the northern end many are down, but there are still a majority standing in most places. The nuts, of course, are stripped from most of those left standing. However, on the less damaged islets there are occasional trees with nuts in drinking condition and some trees are flowering. A surprising thing was the extent to which young palms, with scarcely any trunk, were flattened out, especially where hit by waves; here more were down than standing. Ripe nuts lying on ground are germinating in great abundance wherever they have not been picked up.

Elais guineensis--Planted on Jabor. The only tree was destroyed, apparently by waves.

Pritchardia pacifica--Planted on Jabor. The only tree was destroyed, apparently by waves.

Alocasia macrorrhiza--This was common generally on larger islets; seems not to have been much affected, even where inundated.

Colocasia esculenta--Very rarely noted; seems not to have been much planted by the Marshallese. No effects noted; not inundated.

Cyrtosperma chamissonis--Abundant in taro pits on Pinlep Islet (Pl.IX-b). The leaves were apparently destroyed by the storm but were sprouting up again. Leaves at time of survey up to 4-5 dm. high; not inundated.

Epipremnum pinnatum--Was common in experiment station grounds. Occasional plants survived inundation and are growing again.

Scindapsus aureus--Was common in experiment station grounds. Many plants survived inundation and are growing again.

Xanthosoma sagittifolia--Was occasionally planted around villages. Some plants, at least, survived inundation.

Rhoeo spathacea--Common on Jabor. Inundated but no effects noted.

Agave sisalana--Seen only in one place on Jabor, young plants only. Large ones may have been swept away, if there were any.

Cordyline terminalis--Planted on Jabor; battered by storm and inundation but recovering.

Sansevieria roxburghiana?--Planted on Jabor; no effects noted.

Crinum asiaticum?--Common around villages and home sites; survived inundation; large plants apparently mostly destroyed, smaller ones not flowering but appear healthy.

Hippeastrum puniceum--Rarely planted about dwellings; no effects noted.

Zephyranthes rosea--Commonly planted; no effects noted; survived complete inundation by salt water.

Tacca leontopetaloides--Generally distributed; doubtless some plants too deeply buried for recovery and others removed by erosion, but those in most situations apparently unaffected, even where inundated by salt water.

Dioscorea sp.--Seen by St. John in 1946 on Imroj but not found in 1958.

Musa nana--Not seen with certainty on this survey.

Musa sapientum--Generally planted; shoots destroyed by storm but rhizomes apparently unaffected, even by inundation by salt water, as healthy shoots, up to half mature size, were very common at time of survey.

Canna indica?--Occasionally planted; shoots apparently destroyed but tubers unaffected and new shoots appearing.

Peperomia pellucida--Weed on Jabor; plants seen were probably ones that had grown from seed after typhoon.

Peperomia ponapensis--After typhoon seen only on Majurirek in protected area on western end where there was no inundation; no effects noted, but seen on Imroj in 1946 and not after typhoon.

Casuarina equisetifolia--Planted on Jabor, trees reaching 10 m. height, a few trees uprooted, most of those standing had lost most of their branches and had been pretty well stripped of photosynthetic branchlets, but were vigorously sprouting new branchlets from trunk and remaining limbs, apparently unaffected by inundation.

Artocarpus altilis--(Impractical to distinguish A. mariannensis in dead condition but many of living trees were this.) Breadfruit was a common and important tree on all inhabited islets (Pl.IV-b). It was very badly damaged by the storm (Pls.VI-a,VIII-a,-b). On the eastern islets that were inundated most trees were uprooted and some that were still standing were dead probably from the effect of salt water on the roots. Most of the branches were torn off the trees left standing in all areas examined. In very few places were trees of over 3 dm. diameter at breast height left standing and these were mostly dead. On the non-inundated islets the trunks and few remaining branches were sprouting leafy branchlets. On Majurirek and Pinlep several partly uprooted trees were observed which had many partly grown fruits in good condition. It is probable that most of the standing trees on the south and west islets will make a rather prompt recovery. Seedlings were noted on many areas which had not been inundated and a few on lightly inundated areas. Breadfruit trunks were generally not broken. Either the entire tree was uprooted or branches were split off, mostly at their bases, and small branches torn off of larger branches that remained.

Ficus elastica--Several large trees were growing in Jabor. They survived the inundation and remain standing, but with most of the branches torn off and most of leaves damaged.

Ficus tinctoria--One tree seen on Jabor, uprooted but sprouting from trunk.

Fleurya ruderalis--Common generally in rocky or open places. Doubtless mostly destroyed by typhoon in all places where there was flooding by salt water or exposure to strong wind; but plants have since come up from seeds in most appropriate habitats.

Pilea microphylla--Naturalized from cultivation. Doubtless destroyed by typhoon, but on Jabor and Pinlep has come up abundantly from seed.

Pipturus argenteus--Common in some areas, especially somewhat protected places. Doubtless many plants destroyed by typhoon but some sprouting from battered plants and much seedling reproduction.

Procris pedunculata--Known only from one restricted area on west end of Majurirek Islet where there was no inundation by salt water. Common there but not flowering. No effects observed which could easily be ascribed to typhoon.

Boerhavia tetrandra--Known only from restricted area on east end of Majurirek Islet. No effects observed.

Bougainvillea sp.--Planted around villages and in experiment station, but apparently destroyed by storm except on Kinajon, where two somewhat defoliated plants remain.

Mirabilis jalapa--Planted around villages. No effects noted, but probably present plants have grown from seed since typhoon.

Pisonia grandis--Common, but only small plants seen in most places. On Mejatto one small tree still standing. On Ribon and Lijeron this is the most prominent species. Here some large trees have been uprooted, others are still standing but with many branches blown off and much defoliation (Pl.X-d). Almost all fallen trees and all standing ones sprouting vigorously.

Amaranthus viridis--Common weed, seen only on Jabor and Kinajon, where it is abundant locally, probably grown from seed since the typhoon.

Celosia argentea--Seen on Imroj in 1946, not found on present survey.

Gomphrena globosa--Planted commonly around dwellings even in inundated areas probably grown from seed since the typhoon.

Portulaca oleracea--Generally common. In areas inundated by salt water probably growing from seed since typhoon.

Cassytha filiformis--Common locally, parasitic on other plants. No effects noted.

Hernandia sonora--Occasional fair sized trees, mostly uprooted but continuing to grow, leaves on these trees in inundated areas reduced in size.

Nasturtium sarmentosum--Rare weed on Jabor; no effects noted, but may have come up from seed after inundation.

Kalanchoe pinnata--Local on Imroj and Kinajon, no effects noted but doubtless reduced in numbers on Imroj by burying and erosion.

Albizia lebbek--Planted on Jabor but did not survive inundation by salt water.

Canavalia microcarpa--Common on less disturbed islets, seedlings seen on some eroded areas and deposition areas; no effects noted.

Caesalpinia pulcherrima--Seen planted on Imroj in 1946 but not found during present survey.

Cassia occidentalis--Very local on Jabor, destroyed by storm but seedlings growing in some places.

Crotalaria incana--Dominant plant on many open areas on Jabor, plants grown from seed since inundation are flowering and fruiting abundantly. Deliberately introduced and spread long before typhoon.

Delonix regia--Several large trees planted on Jabor; uprooted by typhoon but still alive, flowering.

Erythrina variegata var. orientalis--One or two large trees planted on Jabor; inundated, uprooted by typhoon but still alive.

Inocarpus fagiferus--Several trees planted on Jabor; inundated, badly battered and defoliated by typhoon but still alive, sprouting from trunk.

Intsia bijuga--Seen on several islands but always blown down by typhoon and sprouting, even in inundated areas.

Leucaena glauca--Abundant on Jabor; survived inundation by salt water, defoliated and upper parts killed by typhoon, now sprouting abundantly from roots andlower parts.

Sophora tomentosa--Seen on Mejatto in 1946, not found on this survey.

Vigna marina--Common on all islets; large numbers undoubtedly buried by gravel and removed by erosion, but in less disturbed places very abundant, probably greatly increased by opening up of shady plantations by fall of trees. Seedlings common on newly deposited gravel.

Citrus aurantifolia--Occasionally planted; in areas inundated by salt water the trees look half-dead but sprouting from trunk, in other areas merely somewhat defoliated.

Citrus maxima--Planted on Jabor but did not survive typhoon.

Citrus sinensis--Planted on Jabor, some plants said to have survived typhoon, not seen.

Citrus reticulata--Planted on Jabor but did not survive typhoon.

Acalypha wilkesiana--Planted on Jabor and Pinlep; no effects noted.

Codiaeum variegatum--Planted on Majurirek Islet; no effects noted.

Euphorbia chamissonis--Common on lagoon ridges on Majurirek and Pinlep Islets; no effects noted.

Euphorbia glomerifera--Common weed on Jabor; no effects noted.

Euphorbia hirta--Very common in waste places on some inhabited islets; no effects noted but plants seen could have grown from seed after typhoon.

Euphorbia prostrata--Local around dwellings; no effects noted.

Euphorbia pulcherrima--Planted on Jabor but did not survive typhoon.

Phyllanthus amarus--Abundant weed on Jabor, Kinajon and Pinlep; no effects noted, but on Jabor could have grown from seed since inundation by salt water.

Ricinus communis--Planted on Jabor but did not survive typhoon.

Allophylus timorensis--Common on Kinajon, Majurirek and Pinlep; seen also on Imroj, Jabor and Mejatto in 1946, not in 1958. Larger trees on Kinajon uprooted but sprouting; others badly battered but growing and flowering; not definitely known to have survived inundation.

Triumfetta procumbens--Common generally, especially in open places, but not seen on Jabor; no effects noted but doubtless many plants buried and eroded away; seedlings common.

Hibiscus esculentus--Planted in garden of imported volcanic soil on Jabor; still growing and fruiting, in spite of inundation by typhoon and periodic inundation of this garden by highest tides.

Hibiscus mutabilis--Planted in Jabor but apparently did not survive typhoon.

Hibiscus tiliaceus--Occasional on inhabited islets. One or two trees knocked over but sprouting; seen on Imroj in 1946 but not in 1958. Abundant in some mangrove depressions but tops usually dead; apparently survived some inundation on Pinlep.

Sida fallax--Seen planted on Mejatto in 1946 but not found in 1958.

Thespesia populnea--Planted on Jabor but apparently did not survive the typhoon.

Ceiba pentandra--One tree planted on Jabor, uprooted and still alive, but doubtful if it will survive; seen on Imroj in 1946 but not in 1958.

Calophyllum inophyllum--Large and conspicuous tree on most islets, especially on lagoon ridges, badly battered by typhoon, more trees uprooted or partly so than not; some blown completely into lagoon. Generally sprouting if some roots still in ground even where inundated. Not seen on two smaller islets except for one seedling on Lijeron.

Passiflora laurifolia--Said to have been planted on Jabor but not found.

Carica papaya--On most islets, but large trees all eliminated by typhoon. Seedlings and partly grown, not very healthy, trees are occasional to common.

Citrullus vulgaris--Planted on Jabor but not seen after typhoon.

Cucumis sativus--Planted on Jabor but not seen after typhoon.

Cucurbita maxima--Commonly planted around habitations, no effects noted but small plants only and very scarce on areas inundated by salt water.

Cucurbita pepo--Planted on Jabor but not seen after typhoon.

Pemphis acidula--Common, especially on most exposed areas, on bare rocks; usually badly beaten and completely defoliated by typhoon (Pl.III-a), but seldom uprooted. Often broken off a few dm. above ground, small branches usually killed (Pl.IX-a). Sprouting abundantly from root crowns and trunks (Pl.VIII-c).

Sonneratia alba--Seen near Sydney Pier in 1946, not found in 1958.

Bruguiera gymnorhiza--Dominant tree in most mangrove depressions; larger trees often dead or with tops dead (Pls.IV-d,V-c), smaller ones, especially seedlings 1 m. tall or less, not much affected by typhoon.

Terminalia catappa--Planted around villages, especially on Jabor, mostly uprooted by typhoon but still alive and sprouting.

Terminalia samoensis--Common, especially on shore ridges and in brushy areas; generally not much injured by typhoon, but some larger plants uprooted though still sprouting.

Barringtonia asiatica--Small groves of several large and many small trees on Mejatto and Imroj islets; most of trees uprooted or large ones with branches torn off; sprouting abundantly from roots, stumps, trunks and large branches, as well as abundant seedlings. These groves were so situated that they got the full force of both wind and waves.

Miconia sp.?--Something identified as this genus was planted on Jabor but not found after the typhoon.

Brassaia actinophylla--Large tree planted on Jabor, badly battered by storm but sprouting from trunk and larger branches.

Polyscias fruticosa--Planted on Jabor but apparently did not survive typhoon.

Polyscias guilfoylei--Seen on Jabor in 1946 but not found in 1958.

Polyscias scutellaria--A few plants in village on Majurirek; no effects noted.

Centella asiatica--Common on several islets, mostly in places not inundated by salt water; no effects noted but plant probably was more common before typhoon, especially on inundated islets.

Jasminum sambac--Planted on Majurirek; no effects noted.

Catharanthus roseus--Planted on Pinlep; no effects noted, but was probably found on other islets before typhoon.

Cerbera manghas--Planted on Jabor; larger trees uprooted but sprouting, saplings locally very common.

Nerium spp.--N. indicum and N. oleander both known from atoll in 1946; plants seen on Majurirek Islet in 1958 not flowering and hence unidentified; no effects noted except lack of flowering.

Ochrosia oppositifolia--Seen only on the seaward side of the west end of Imroj Islet, where there were several fair sized trees. Most of these had been knocked down and the places where they were growing covered by a thick gravel deposit. Two, almost at the extreme end of the seaward side, were still standing, badly battered but with some green leaves.

Plumeria rubra--A few shrubs or small trees planted around dwellings and graves. Those on Mejatto, Majurirek and Pinlep showed no signs of damage, but one on Kinajon was partly uprooted. That on Mejatto was on a small section that was not touched by waves. That on Kinajon was not inundated either, except possibly by lagoon waves.

Ipomoea batatas--Seen planted on Imroj in 1946 but not found in 1958.

Ipomoea littoralis--Occasional locally on Jabor and Pinlep; seen on Imroj in 1946 but not in 1958; no effects noted but on Jabor probably much reduced by inundation and on Imroj probably eliminated.

Ipomoea pes-caprae ssp. brasiliensis--Seen only on Jabor, except for a single seedling on Ribon. In 1946 this was one of the most abundant plants on the narrow strip south of Jabor and around Sydney Pier. Now there is little of it to be seen, as might be expected, since this was where inundation and stripping of loose material were most severe.

Ipomoea tuba--Seen only on Kinajon and around large banked oil tank at Sydney Pier. No effects noted, but it would have been expected to be more abundant.

Cordia subcordata--Common generally, especially around periphery of most islets; few trees actually uprooted but several somewhat tipped over, some dead or at least leafless above, but with vigorous lower branches flowering even where there was severe inundation; seedlings common on deposited material.

Tournefortia argentea--Seen on all islets visited, on most of them common around periphery; variously battered by typhoon, uprooted or branches broken off, usually sprouting vigorously; seedlings abundant on newly deposited or disturbed ground.

Clerodendrum inerme--Occasional, locally common; defoliated but not badly hurt by typhoon, recovering even where inundated by salt water.

Lantana camara--Said to have been planted on Jabor but apparently did not survive typhoon.

Premna obtusifolia--Nowhere common; most plants severely battered, those seen on Mejatto were only stumps with sprouts, but perhaps cut before typhoon; plants on Majurirek less damaged than others.

Stachytarpheta urticifolia--Common weed on Jabor, probably all plants seen grew from seeds after typhoon.

Ocimum sanctum--Planted on Pinlep; seen on Imroj in 1946, not in 1958; no effects noted but probably eliminated from Imroj.

Nicotiana tabacum--Growing on Jabor in 1946, not seen in 1958.

Physalis angulata--Abundant weed on most larger islets; probably grew from seed since typhoon.

Solanum nigrum--Common weed on Jabor and Pinlep, probably grown from seed since typhoon.

Jacaranda filicifolia--Planted on Jabor but apparently did not survive typhoon.

Beloperone guttata--Planted on Jabor but not found after typhoon.

Blechum brownei--Abundant weed locally on Jabor, probably grown from seed since typhoon.

Hemigraphis reptans--Rare, only seen on lagoon side of Pinlep; no effects noted.

Pseuderanthemum carruthersii--and its variety atropurpureum. Planted very generally around habitations; suffered rather little damage even from inundation, except where bent down and partly buried by gravel sheets, even here flowering freely.

Dentella repens--Locally common on Jabor; said to have appeared rather recently in field of bananas brought from Kusaie and Ponape; no effects noted, plants probably from seed after typhoon.

Guettarda speciosa--Common on most islets; most trees either badly broken or uprooted, some of them sprouting, seedlings common.

Hedyotis biflora--Occasional on Imroj, Mejatto and Jabor in protected places; no effects noted, but probably much less common than before typhoon.

Ixora casei--On Imroj before the typhoon, not seen after, apparently did not survive typhoon.

Ixora fraseri--Planted on Jabor but did not survive typhoon.

Morinda citrifolia--Common on most islets, plants mostly bent down or broken off by typhoon but sprouting vigorously, several very large plants uprooted; seedlings occasional.

Hippobroma longiflora--Weed in Jabor, one plant seen, in flower, during survey.

Scaevola sericea--One of most common plants on most islets; doubtless greatly reduced in numbers by erosion of seaward ridges, many plants battered but sending out leaves; seedlings common.

Adenostemma lavenia--Seen on Imroj in 1946, not found in 1958 except one plant seen on Kinajon Islet.

Ageratum conyzoides--Known on Jaluit and reported by Germans and Japanese, but not found in 1946 or subsequently, until one small plant was collected just above lagoon beach on Jabor.

Cichorium endivium--Said to have been planted in garden on Jabor, not found.

Spilanthes iabadicensis--Said to have been a weed on Jabor, not found.

Synedrella nodiflora--Weed, common to occasional on Jabor, Kinajon, and Pinlep; no effects noted, probably grown from seed after typhoon.

Tagetes sp.--A few plants seen in garden on Majurirek, no effects noted but may have been planted after typhoon.

Vernonia cinerea--Common weed on most inhabited islets; no effects noted, but plants could have come from seed after typhoon; not seen on Imroj where it was found in 1946.

Wedelia biflora--Common on all islets visited except Lijeron. Abundant on parts of wider ones; no effects noted, but doubtless greatly reduced in places eroded by waves and where much gravel was deposited; probably much more abundant than formerly in places where coconuts were knocked down but which were not inundated by salt water (Pl.VIII-b).

X. TERRESTRIAL FAUNA

J. L. Gressitt

The effect on the terrestrial fauna by Typhoon OPHELIA was much less than expected in terms of the general damage to the atoll. On an atoll the size of Jaluit, it seems apparent that even with very severe damage to parts of the atoll, in most groups of land animals the percentage of survival of species is fairly high, at least in one part or another of the atoll. Thus, as those parts of the atoll that lost much of their vegetation and soil regain a normal vegetational situation, presumably the faunal picture will regain its previous status within a reasonable period. The length of this time period will be largely controlled by distances and wind directions, in relation to less affected portions, and by the habits and habitats of the animals and their vagility (natural ability for dispersal), as well as by rate of revegetation and by human travel.

It is felt that the natural populating of oceanic islands by insects is effected primarily by passive transport in air currents. In the case of mid-Pacific atolls the potential sources of additional species of insects are distant and therefore strongly limited. Also, the number of species of insects, and other animals, that an atoll can support is strongly limited by the lack of many types of environments present on high islands, and by the limitations of flora, soil, and fresh water. If some species were exterminated from the atoll as a whole, repopulation by those species not associated with man might be very slow.

Mammals: These on Jaluit were limited to rats, except for man and his domestic dogs, cats, and pigs. Possibly three kinds of rats* were present, or at least intermittently present, but precise data are lacking. Rats suffered considerably from the typhoon -- perhaps more than most groups of animals. Apparently rather few survived. None were seen during the survey, and only slight evidence of one was noted on Jabor.** Those presumably present earlier were *Rattus rattus*, *R. norwegicus* and *R. exulans*. One opinion expressed was that the rats were largely exterminated, at least on Jabor, but that repopulation had taken place from ships which had come in since the storm. Pigs and pets were only in small part lost during the typhoon. Only sixteen of the 1,300 people on the atoll were killed (two of these died of exhaustion immediately following the storm).

Birds: Birds were not greatly affected by the typhoon. Local residents stated that although some dead birds were noticed after the storm, in general the number of birds present afterwards did not appear to be

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* Mice, Polynesian rats and common black or brown rats were previously reported from Jaluit by Schnee (1904) and Kuroda (1934), Norway rat (as *Mus decumanus*) by Finsch (1893, p. 122) --F.R.F.

** Coconuts, gnawed open by rats, were seen on Majurirek I.--F.R.F.

materially decreased. During the week's observations, two land birds with rather few Marshall Is. records (New Zealand cuckoo and Micronesian pigeon) were observed. During a visit to "Bird I." (Lijeron), large numbers of birds were seen, particularly White-capped Noddies, Brown Boobies and Frigate Birds, the former with abundant nests (of Pisonia leaves on twigs), eggs, and young birds. One White Tern egg was seen. Birds seen were as follows (in addition to those listed below, 13 other species are recorded from Jaluit and 25 from the Marshalls as a whole by earlier authors):

Species not previously recorded at Jaluit Atoll are starred (*). Letters refer to the places of observations as follows:

E -- Majurirek (Elizabeth)	L -- Lijeron
I -- Imroj	M -- Mejatto
J -- Jabor	P -- Pinlep
K -- Kinajon	R -- Ribon

*Puffinus pacificus cuneatus (Salvin) -- Wedge-tailed Shearwater . . . . J

*Phaeton lepturus dorotheae (Mathews) -- White-tailed Tropic Bird. . . . P

*Sula leucogaster plotus (Forster) -- Brown Booby. L

*Frigata minor minor (Gmelin) -- Pacific Man-O'-War (Frigate Bird) . . . I

Demigretta sacra sacra (Gmelin) -- Reef Heron . . . . .MRJE

*Pluvialis dominica fulva (Gmelin) -- Pacific Golden Plover. . . . . .IRJP

Numenius phaeopus variegatus (Scopoli) -- Whimbrel. . . . . J

Heteroscelus incanus (Gmelin) -- American Wandering Tattler. . . . . .KJPE

Arenaria interpres interpres (Linn.) -- Turnstone . . . . JPL

Thalasseus bergii pelecanoides (King) -- Crested Tern L

Anous stolidus pileatus (Scopoli) -- Common Noddy . . . . MRKEPL

Anous tenuirostris marcusi (Bryan) -- White-capped Noddy. . . . . MRJKEL

Gygis alba candida (Gmelin) -- White Tern . . . . MRJEPL

Ducula oceanica oceanica (Lesson and Garnot)-- Micronesian Pigeon . . . K

Eudynamis taitensis (Sparrman) -- Long-tailed New Zealand Cuckoo. . . .JL

Reptiles: Terrestrial reptiles in the Marshalls include only lizards.

These do not seem to have been seriously affected by the typhoon. Large populations of the small striped skink were seen on most islets, and also fair numbers of geckos and the green, black and slender blackish brown skinks. The lizards are the most important predators of insects in the Marshalls, where perching birds are absent. Thus with any diminution of

the lizard population, serious consequences might result with an abundance of insects resulting. The lizards observed are as follows:

Lepidodactylus lugubris -- Small House Gecko . . . . J

Gehyra oceanica -- Big Tree Gecko . . . . J

Dasia smaragdina smaragdina -- Green Skink. . . . . EJ

Emoia cyanura cyanura -- Striped Skink. . . . . MRIJEPL

Emoia arnoensis -- Black Skink. JPK

Emoia boettgeri (?) -- Slender Skink. . . . . P

Amphibians: There are no native amphibians, and the giant toad (Bufo marinus) has apparently not been introduced to Jaluit.

Fresh water fish: There are no native fresh water fish in the Marshalls. Gambusia minnows have been introduced to Jaluit for mosquito control. These survived in at least one cistern (elevated about 1 m.) in the middle of the wide portion of Jabor. Those in non-elevated water tanks apparently were killed by salt water inundation.

Insects: In general, insects seem to have been very successful in surviving the typhoon. About 225 species of insects and about 23 species of other terrestrial arthropods were collected during the survey. The number of species surviving is undoubtedly very much larger. Insect collections may be incomplete for the atoll as a whole because we worked mainly on islets more heavily hit by the typhoon. Various traps (light trap, fly traps, and AEC fallout sheets) were operated on Jabor, but strong winds, rain and a bright moon interfered with their functioning. It is estimated that the normal insect fauna of Jaluit should number about 500 or more species. Probably very few, if any, of these were eliminated by the storm. But one week, with much time spent in reaching the different islets, was insufficient for an adequate survey. The insect population appeared to be reviving and increasing rapidly. With short life-cycles for many groups of insects in this latitude, some species had undoubtedly already multiplied their populations many fold in the $3\frac{1}{2}$ months since the typhoon.

In abundance of individual species, there was great variation, partly related to normal trends, but partly accentuated by the typhoon. Soil insects, normally weakly represented on atolls, were particularly scarce, especially on islets that were inundated.

In some limited spots on less affected islets, and on broader parts of more disturbed islets, litter (rotting vegetation) was found which contained spring-tails, phorid flies and maggots of other flies. Some of this material consisted of rotting Pandanus leaves (even of lost roofing), rotting leaves of downed coconut palms, or old rotting logs. As mentioned elsewhere, much soil, humus, and dead vegetation was washed into the lagoon, besides many living trees. With the superabundance of newly killed trees, the populations of many of these scavenging insects, reduced

by the typhoon, will undoubtedly undergo further great increase. On the other hand, the burning frequently practised by the Jaluit people (noticed particularly in the case of Majurirek) will considerably restrict these insects, as well as humus production, which are related. Insects that live under dead bark survived reasonably well, and were found to be breeding up very large populations because of the great abundance of killed and fallen trees, particularly breadfruit trees.

In the many old Japanese water cisterns, or oil tanks, as on Jabor, considerable breeding of some insects was observed, even in tanks which had been overrun by salt water. Most of these tanks now contain rotting plant debris, and many of them support numerous mosquito larvae (Culex quinquefasciatus), as well as larvae of a pale tendipedid (chironomid) fly, a dark ephydrid fly, a damsel fly and two species of dragonflies. The day-biting mosquito (Aedes marshallensis) was much rarer than the night-biting Culex, and was seen breeding in a hole in the side of a downed coconut palm.

House flies were quite abundant, together with other filth-flies, particularly sarcophagids, and to a much lesser extent calliphorids. The breeding places were not too well determined, other than latrines. In some villages, flies were being trapped in large numbers in screen fly traps baited with dead fish.

The insects which were encountered in perhaps greatest numbers were a species of pale broad leafhopper (Exitianus fusconervosus) on grasses, herbs and some trees; a dark-striped lygaeid bug (Nysius pulchellus) on Physalis, Cyperus, Phyllanthus, Sorghum, grasses, Morinda, and other plants; a slender predaceous bug (nabid) often on these same hosts and on Crotalaria; certain small species of flies, mainly seen resting on leaves or flowers of Terminalia, Hernandia, Tournefortia; certain species of small ants on various plants; and several species of moths. The moths included several abundant microlepidopterans and pyrales on Terminalia, Hibiscus, etc. and some noctuids, some of which often heavily defoliated Wedelia, and also some on Pemphis, etc. The ubiquitous day-flying moth, Utetheisa pulchelloides, was seen on Tournefortia on all islets. The single butterfly species (with several color forms), Hypolimnas bolina, was very abundant on the wide part of Jabor, and on the less affected islets. An abundant beetle, besides those found under bark of dead breadfruit trees, was a small anthicid, probably a predator, on Sorghum, Cyperus, etc.

One group of insects which was noticeably scarce was the locusts. Only one specimen was found, whereas one or more species are generally very abundant on most atolls in grassy areas. The long-horned grasshopper, Physis, was also quite rare, and seen mostly in the nymphal stage, indicating population build-up from a low level.

Spiders: About four species were moderately abundant, a few others rare. Two species of centipedes were taken, and one scorpion. No millipedes were taken except for a minute questionable form.

Terrestrial Mollusks: Terrestrial mollusks are scarce in species in the Marshalls and mostly quite small. Because of their protective devices, they did not suffer much from the typhoon. Only in a few cases were any

found to be abundant. On Kinajon Islet a small species of snail was very abundant on leaflets of young coconut palms, as well as on Canavalia vines entangling the young palms. A more elongate land snail was found in several spots (see Appendix II).

Fresh water or brackish water snails of about three species were found in the mangrove pools on Majurirek, Pinlep and Imroj Islets.

Other terrestrial invertebrates: Few other strictly terrestrial forms were encountered. No earthworms were seen. Isopods and amphipods were scarce, aside from shore-living or mangrove-pond species. A few small shrimps were found in mangrove swamps:

Ceridena sp. (Ateidae) -- in mangrove pond, Imroj

Leander sp. (Palaemonidae) -- in mangrove pond, Majurirek

Metabetaeus minutus (Alphaeidae) -- in mangrove pond, Jabor, Mejatto, Imroj

Land crabs included Sesarma, Grapsus grapus tenuicrustatus, and Metasesarma rousseauxi.

XI. SUBMARINE EFFECTS OF THE TYPHOON

A. H. Banner

With only minor variations, the coral reefs of Jaluit Atoll are generally similar to those of other atolls. On the ocean side of the windward islets the seaward margin of the reef flat is serrate with surge channels; however, the algal ridge, so often prominent on windward reefs, was not seen in any of the sectors examined. Behind the outer front of the reef, the gradually sloping reef flat, exposed at low tides, is smooth; its surface is composed to a large extent of encrusting coralline algae. Landward the flat gives way to the eroded beach rock formation that reaches to near high tide level.

On the lagoon side of the windward islets the beach is composed of beach rock, coral shingle, or sand, depending upon exposure to prevailing winds, waves, and currents. At the low tide level there is a sandy terrace, either a reef flat covered by sand or a deeper sand deposit or apron, bearing scattered living corals; this terrace may slope off gradually to water ten or more feet deep, or it may abruptly change from a shallow shelf to a steep slope into deeper water. This lagoon slope is also of either sand or coral gravel, but has a greater abundance of growing coral, often in massive groupings of many species.

On the lagoon side of the leeward islets the conditions are somewhat similar to those of the lagoon side of the windward islets, but with more extensive sand flats. On the ocean side of the lee islets the reef is markedly different from that of the windward side, being broader, with the surface of the reef flat less smooth, and with the outer edge sloping more gradually into deep water without any definite development of surge channels.

All of these areas were examined except the front and foreslope of the windward reef. In all areas examined very few changes due to the storm were noted.

There was evidence, however, that the area not examined suffered rather extensive damage from the storm. Because of the high waves during the visit of the group it was dangerous to venture to the outer edge of the windward reef and impossible to explore the surge channels. Presumably that portion of the reef was originally similar to the windward reefs on other atolls: from the outer reef flat the surge channels would be separated by buttresses; in the actual surf region there would be almost nothing but encrusting coralline algae; from the depth of about five feet and down there would be an ever-increasing covering of living and dead corals including Pocillopora meandrina and shelf-like species of Acropora (for example A. spicifera) both on the buttresses and in places on the walls of the surge channels. Both the buttresses and the surge channels would level off at a shelf about fifteen or twenty feet deep; the shelf would be in the neighborhood of one hundred or more feet wide, sloping to about 40 feet deep; there the bottom would drop abruptly away to the greater depths. Scattered on the shelf would be many heads of living corals, again predominantly species of Acropora; among the bases of these

heads and massive coral growths would lie a thick layer of dead coral fragments broken from the growing reef front during normal storms.

Lacking direct observation of this section of the reef, the damage to it must be deduced from the bars of boulders and gravel lying on the reef flat. This bar has been described in detail earlier (See p. 39); here it will suffice to state that it is a new feature along the windward beaches examined. In a typical section near Jabor it was about 60 feet wide, up to 8 feet high, and about 100 feet from the reef edge and 30 feet from the beach rock.

The composition of the bar varied from place to place, but the bulk of its components appeared to come from the reef front and foreslope. Evidence of this origin includes the following:

1. The presence of many fresh pieces of coral with the calices uneroded, and in some instances with the branches unbroken. These corals, including Pocillopora meandrina and Acropora spp. occur normally only in the surf zones of reefs.

2. The presence of the remains of surf inhabiting organisms, such as the rock oyster, Chama, and the slate-pencil sea urchin, Heterocentrotus. The shells of the oysters were not beach-worn but fresh with the nacre of the surface unweathered. Numerous fresh, uneroded spines of the urchin were found, and in one case a section of the test with spines attached was seen.

3. The presence, on old dead fragments of coral and over-grown coral heads, of fresh bright red patches of colonial Foraminifera, a form that grows abundantly upon the fragments found on the outer shelf of the reef.

4. The presence of the largest coral boulders on the reef at the seaward edge of the bar, while the landward edge was composed of the smallest fragments.

5. The report by the Marshallese that for a period after the typhoon the bars gave off a strong stench of decomposing organic material, a condition which could not obtain were the bars composed of long-dead corals from the boulder ridge.

However, not all of the material in the bar originated in the outer reef area. On Jabor and Mejatto, where the bar was most carefully examined, the following were found:

1. Old blackened coral fragments that had obviously been buried in the soil of the islet.

2. Coral, usually old and partially overgrown but, in some instances, fresh and recently killed, of species characteristic of lagoons, for example Fungia scutaria.

3. Rounded basaltic rocks with calcareous deposits on the

surface, brought by man to the atoll either as ballast or as ornamentation, and pieces of iron and cement (several of which had fresh tubes of marine worms attached), that would most logically be found in the lagoon where ships anchored, not off the turbulent windward reef.*

The bulk of the material in the bar was not recognizable as to source; however, as, of the pieces that could be so recognized, most were from beyond the outer edge of the reef flat, it is logical to conclude that most of the bar was from there.

At low-low tide level and below on the lagoon side of the windward islets few storm effects could be seen. Those few that were observed include the new offshore bars, either exposed at low tide or a few feet below the surface; the presence of storm-carried trees on the reef flats and on the slopes beyond the reef flats; and the presence of fine organic sediments in a few restricted areas.

Those familiar with Jaluit Atoll state that the offshore bars along the lagoon reef flat were built during the typhoon. The highest and most conspicuous of these was found near the outer edge of the lagoon reef flat off the northeast end of Jabor. The bar started in the north close to shore on the slope leading to the depths of the pass and continued southward, swinging away from the islet and lying near the outer edge of the reef flat, and finally curved back towards shore near the anchorage of Jabor in a rough "C"-shape. Its base rested on the reef flat slightly below the low-low tide level, and its top rose two to three feet, the top thereby being exposed at mid-tides. The slope towards the lagoon was gradual; the slope towards the islet was abrupt, being at the approximate angle of repose. The bar was usually about 50 feet wide. It was composed of rubble derived from long dead coral and other calcareous debris mostly of small size, an inch or less in diameter, several inches long; scattered about its surface were some larger pieces, up to about 6 inches in diameter. The source of the bar material was questionable, for all was old and discolored; however it would be logical to presume that some, at least, came from the northwestern tip of Jabor, which was cut away in the typhoon, and other portions, probably the bulk, came from the channel slope where similar pieces may still be found. The shape of the bar, no matter what the source, indicates it was formed by onshore waves from the lagoon.

It should also be noted that on the reef flat behind the bar, and at some spots in the bar, there were occasional larger heads of dead coral, up to several feet in diameter. These must have been carried on to the reef flat by previous storms, for all examined were found to be surrounded by delicately branching and unbroken live coral.

A bar, about 450 feet from shore, was found in the lagoon south of the anchorage at Jabor. It was similar in size, shape and composition to the one north of the anchorage, but differed in that its base was lower, and its top, about two feet higher than the base, lay near low-low tide level.

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* Pieces of glass were also found (see pp. 12, 23).

Aerial inspection showed that the reef was an off-shore feature of most of the length of the long isthmus connecting Jabor with Jaluit. The source of the material in the bar could not be ascertained, but it is likely that it came from the detritus of the gradual slope into the depths of the lagoon.

No offshore bars were noted off the northern and leeward islets.

Along the shore, in the high intertidal zone, and continuing out to deep areas of the lagoon, were found storm-carried trees with their root masses intact. Most of the trees were either coconut or pandanus. Near shore most were lying on their sides, but some near shore, and all in the deeper water, were standing erect; the ones in deeper water were obviously buoyed by the trunks and sunk by the rocks captured in the root mass. Off the southern portion of Jabor, the only deep water inspected, they were found up to a thousand feet from shore, resting on a bottom eighty feet deep.

In only a few places were sediments composed of organic matter observed. They were most conspicuous in the lagoon off the middle of Mejatto. Here, on a ripple-marked sand bottom in ten to twenty feet of water, the depressions between the ripples contained thin deposits of loose black sediment, so low in specific gravity that it was stirred by the slight currents. Identifiable fragments of the sediment appeared to be decomposed plant material. No similar deposits were seen in gravel portions of the bottom.

Aside from these features and the bars built out from land, no observable change was found below the low-low tide level in the lagoon. In the zone of extreme low water even the delicately branching lagoon corals were unbroken. In none of the sectors examined were there any deposits of fresh sand, as indicated by the absence of recent sediment burying the lower portions of coral heads or lying between the bases of the dense coral patches on the reef flats, as for example within the new bar off the northern end of Jabor.

Similarly, inspection of both the ocean and lagoon sides of the leeward islets showed no obvious damage below low-low tide level. The gradually sloping flats on the lagoon side were of sand and had isolated massive complexes of many genera of corals, and these, including the fragile staghorn coral (*Acropora grandis*), were not broken. On the ocean side beyond the edge of the reef flat the gradually sloping bottom, covered with a continuous layer of growing coral, also showed no signs of damage. It is true that on the ocean reef flat there were scattered boulders of dead coral and that in the depressions on the flat there were coral fragments; but all of the former appeared to have rested long in their present locations, and fragments of coral, often rather fresh, are a common feature of such depressions.

XII. MARINE RESOURCES

A. H. Banner

There is nothing to indicate a lessening of the fishing potential of Jaluit except possibly on the outer slopes of the windward ocean reef. The windward reef is not used for fishing except for torch fishing at night and in times of exceptionally calm water. The actual fishing potential within the lagoon may increase, because additional fertilizer in the form of organic detritus has been carried into the lagoon where it can stimulate the production of fixed algae and phytoplankton. Moreover, the masses of tree roots in the water are already covered with a film of algae that is being browsed upon by small herbivorous fish and the roots offer hiding places for small fish. These small fish are the food of the larger carnivores.

The Marshallese on the atoll have reported that even immediately after the typhoon the fishing was better than before. It is likely that this merely represents a greater fishing effort rather than any true increase in larger fish, for if the postulated mechanisms do increase the fishery, it would be only after a lag of a number of months.

If there is an increase in productivity in the lagoon, it should last for several years, the length of time for the recycling nutrients to be flushed to sea and for the root masses to decompose entirely.

Another possible effect of the typhoon would be to increase the toxicity of the fish in the lagoon. Before the typhoon, Jaluit Atoll had the reputation of having more poisonous fish than any other atoll in the archipelago. Several workers (Randall 1958, Dawson 1959) have suggested, without any direct proof, that the toxicity of the fish results from direct feeding upon poisonous algae, or feeding upon herbivores that eat the poisonous algae. If the fertilization of the lagoon increases the amount of the hypothetical poisonous algae there may be an increase both in the toxicity of the species now known to be dangerous and in the number of species found to be toxic. However, the Marshallese eating the fish from the lagoon report no change in toxicity patterns.

Note: For information on poisonous fishes in Jaluit reference may be made to Hiyama 1943 and Bartsch et al 1959.--Ed.

XIII. POPULATION AND ECONOMY OF JALUIT

J. B. Mackenzie

Population and economy prior to November 8, 1957

Population Distribution

Prior to World War I, the Marshall Islands were under German Administration with headquarters on the island of Jabor, in Jaluit Atoll. After 1918, the Marshall Islands were officially turned over to the Japanese, who took over all German properties in the Marshalls under a League of Nations Mandate. The Japanese Civil Administration continued to use Jabor as headquarters for the Marshall Islands.

The Japanese immediately started setting up a large center in Jaluit, with independent trading companies and small businesses run by the Japanese themselves. They drew their man-power from the surrounding islands for the labor needed to build and maintain their center on Jabor. This, of course, resulted in large forces of Marshallese coming into Jaluit from the other atolls. The attraction of Jaluit to the Marshallese continued up into the 1930's. After 1935, with the Japanese Military moving into the Marshalls, the need for labor forces again started a sharp rise of population influx into Jaluit.

Two large concentrations of people were at Imroj Islet and Jabor Islet. The islet of Imroj was established as the Japanese Naval Air Station, where large labor battalions were put to work on the building of a major air station. Jabor became the headquarters for the Army, with small Army units stationed on the larger islets in Jaluit Atoll. Just prior to the war, the Civil Administration started construction of a new center three miles south of the Army center on the islet of Jabor.

United States Forces moving across the Pacific to the Marshalls in 1944 cut off the Japanese supply lines to the large military atolls, causing another shift in population. It was necessary to move people to islets where they could get native foods. All imported food items were cut off from the Marshallese to enable the military to feed their army and navy personnel. With the U. S. forces striking in the Marshalls and creating a shortage of food for the Japanese military forces, the Marshallese were again moved to larger islets where they were put to work gathering food and where they could be under close surveillance.

The surrender of Japan in 1945 and the taking over of the administration of the Marshall Islands by the U. S. Navy caused another shift of people. Imroj Islet was set up as the central government seat for the Marshallese in Jaluit Atoll. This shifted the main concentration of people to Imroj. The approximate population of this village numbered between three and four hundred. This was considered the main village on Jaluit, with smaller villages or settlements scattered throughout the atoll.

The atoll is divided into four divisions, which could be called political centers, or as referred to by the Marshallese, "Mountain

Marshalls" (which in our local government are called precincts). The population in these four divisions are usually concentrated on one large islet within each section, with one or two families on the smaller islets that are part of this section and many of the other islets uninhabited. The four centers are: 1) Jaluit Islet on the south tip including Jabor, Ewo and Moni islets, 2) Majurirek Islet off the south-west pass, with Ai, Pinlep, and some small uninhabited islets, 3) Wotle Islet in the northern part of Jaluit including several uninhabited islets south-east up to Mejatto Islet, and 4) Imroj Islet, the atoll council seat, including the islets south-east of her down to Enejet Islet, across the pass from Jabor.

Total population of Jaluit was approximately 950, as shown by the Navy census taken in 1949; Imroj had the greatest concentration of 300 to 400 people and the other three divisions with about 150 people in each.

In 1955, the Marshalls Import Export Company, the Protestant Intermediate School, the Catholic Mission School and the Trust Territory's Jaluit Project moved to Jabor, causing a shift of population within the atoll. Jabor, which had been uninhabited for almost ten years, came to life again and the population at the end of 1956 was 250. The Kwajalein Import Trading Company moved into Jabor in the early part of 1957, increasing the population to 280 people. The large majority of the people who moved to Jabor were from the surrounding islets of Jaluit, with probably 20 people coming from other atolls in the Marshalls.

The Marshallese have always considered Jabor as the main islet in the atoll, since the Germans and Japanese built and developed there the administrative center for the Marshalls. It was, therefore, only natural for them to return to Jabor in large numbers. The only reason that the council seat was not moved over to Jabor was the scarcity of private land owned by the Marshallese. Most of the land on Jabor is government owned with title coming all the way from German times. The government needed all of its land for an experiment station in lowland agriculture.

The rebuilding of Jabor caused a constant movement of people across the lagoon into Jabor. The two trading companies and the headquarters of the Trust Territory representative at Jabor changed the port of call for ships from Imroj to Jabor. The people came across on their sailing boats and canoes with copra to sell to the trading companies and returned to their islets with trade goods. Many of the people came to Jabor to wait for a ship or just to be there while the ship was in port. At such times, there were anywhere from four to five hundred people on the islet.

There has always been a considerable amount of movement within the atoll itself. Each year for the Christmas holidays, people from all of the islets go to Imroj. The majority of the people belong to the Protestant Church and move to Imroj where the central Protestant Church and Minister are located. At the same time, election of new officers is held for the atoll. There are usually seven to eight hundred people present on Imroj during the holidays. They move in with all of their worldly possessions, prepared to remain from one to two months until the limited available transportation can take them home again.

Food resources

I. Indigenous

a. Agriculture

1. The primary food resources which the people depend upon are locally grown and collected. The main food items used in each household are coconuts, jekaro (coconut sap), breadfruit and pandanus. Breadfruit is a seasonal fruit. Most breadfruit trees bear twice a year. The heaviest crop is from May to July with a very light crop in December and January. The surplus breadfruit is usually preserved and used between seasons. Pandanus, another seasonal food, is used between breadfruit seasons. The pandanus can also be dried and kept for long periods of time. Coconuts are used daily by each household. The dry, ripe coconut is grated and the milk squeezed out, to be used with other foods. The iu (embryo) is taken from the sprouted nut and is usually eaten right from the nut or cooked for a meal. The sweet water of the young green coconut is used for drinking and the soft meat is eaten with a spoon. The flesh of the dry, ripe nut is also eaten at meals.

2. The secondary foods are taro, banana, and arrowroot which are usually used between breadfruit and pandanus seasons. There was very little cultivation of taro in Jaluit and it was found only on a few of the islets. The coconut was emphasized by the Japanese and many of the taro pits were put into coconut groves. Arrowroot is cooked like a potato and eaten at meals with other foods. The people also make a candy by grating the arrowroot and boiling it into a spongy ball then covering it with freshly grated coconut meat. Most of their bananas are eaten between meals and occasionally cooked and eaten at meals. There is also a small amount of sweet potato and pumpkin grown and used as a secondary food. Limes and papayas are grown in very small amounts. Lime juice is used to spread over raw fish. Papayas, when ripe, are usually only eaten by children while the green papayas are cut up and boiled as a vegetable.

b. Fisheries

1. Fish has always played a very important part in the Marshallese diet. It was their sole source of protein before livestock were introduced. The early method of catching fish with a fish trap is very rarely used today. Most of the fishing is done by hand line and trolling in the lagoon. When the weather permits it, they fish for tuna on the outside of the lagoon off the deep water passes.

Most of the edible fish are caught in the lagoon or on the outer reefs, with nets or, at night, with coconut torches. The night fishing along the reefs is usually done in groups of three or four men, when the tide is low. The fish caught on the outer reef are of many varieties that can be found all through the south Pacific. The fish caught in the lagoon are of various types, some of which are poisonous. The Marshallese in Jaluit know which are the poisonous types and are very rarely poisoned. Some of the types caught in the lagoon are the sea bass, parrot fish, surgeon fish, mackerel, squirrel fish, trigger fish, butterfly fish, mullet and sardines. The red snapper family is also a very

large group that is caught in the lagoon, but the majority of them are poisonous. This same fish is a safe food in many lagoons of the Marshalls.

2. Shell fish in the Marshalls can be considered as secondary, as the amount caught is negligible and is not eaten daily. The clams along the inside reefs are gathered and usually placed in salt brine, and kept in bottles, and eaten when no other protein food is available for meals. The larger shell fish are occasionally caught and eaten. Langusta (Lobster) are rarely caught in Jaluit. There is an occasional langusta gathering, which is usually held during the night, with torches.

II. Food imports

The Marshallese import a great part of their food, as they have become accustomed to do from Japanese times. The trading companies from Japan opened up a whole new line of imported foods and consequently the Marshallese depend on the import of these foods. A small amount of these items was introduced during the German times, so the people were somewhat familiar with new foods. In order to stimulate the production of copra to meet the demand in Japan, consumption of store food was encouraged.

There are two large trading companies in the Marshalls: Marshalls Import Export Company and Kwajalein Import Trading Company. There are numerous smaller companies and private individuals that import trade goods. The two large companies import the greatest amount of foods. Marshalls Import Export Company has been granted the only Trust Territory license to purchase copra for export. The same company owns and operates a trading vessel in the Marshalls, and the Trust Territory operates an AKL to help cover the entire Marshalls.

The imports of food from the United States and other countries in the world total $414,000.00 per year for the entire Marshalls. Jaluit Atoll annually imports about $25,000.00 worth of foods. The main imports are rice, flour, sugar, canned milk and canned meats and fish.

Cash crops and products

1. Copra

Copra is the largest export item that the Marshallese have in Jaluit. Before the typhoons struck Jaluit in November 1957 and January 1958, they exported approximately 500 to 600 tons of copra a year at $100.00 a ton. This in dollars was $50,000.00 to $60,000.00 a year and was the largest source of income.

The men in the atoll do most of the work in producing copra with the women helping them. The coconuts are husked and carried from the groves, usually to the homes, where the women open them and spread them out to dry. The nuts are left in the sun for two or three days after which they are cut into small pieces and left on mats to dry. The coconut meat is spread out each morning and taken in every evening or when it rains. When the meat is thoroughly dry, it is packed into bags and stored under the house or taken to the trading company. The trading company usually exchanges the value of the copra for trade goods, or if the producer chooses, gives him cash for the copra brought in.

2. Trochus

Trochus is considered the second cash crop, but the total amount of money received for the gathering of trochus is relatively small in comparison to copra. About two tons of trochus are harvested each year in Jaluit. The world market for trochus fluctuates to such an extent that it may be $800.00 a ton one year and $400.00 the next. The trochus season comes once a year and usually falls in July or August. The length of season for gathering trochus is limited by law to fifteen days in Jaluit. Trochus is found in three areas of Jaluit Atoll where the divers gather them and leave them on the beaches until the animal inside the shell either rots or is eaten by ants. The harvest is then taken into Jabor to be sold at the trading companies. Trochus under three inches diameter are not to be taken from the beds, and a heavy fine is imposed if anyone is caught with shells under three inches.

Cash uses

The people of Jaluit use their cash primarily for the purchase of imported food items such as rice, flour, sugar, canned milk and canned meats and fish. The balance of their money is usually spent on soft beverages, tobacco, clothing, building materials, boats, boat parts and gear, kerosene, household items and sundries such as perfume, hair oil and soap. Most of this merchandise is purchased from the trading companies' representatives on the boats that come into the area. Many of the people order radios, ready-made dresses, and other miscellaneous items from mail order houses in the United States.

Effects of typhoons LOLA and MAMIE (November 8 and 14, 1957)

The effects of these two typhoons were felt very little by the majority of the people on Jaluit. Damage from these typhoons was relatively slight and was practically confined to Jabor. In Typhoon LOLA, the south end of the islet was under water, but there were little damage and no injuries. Typhoon MAMIE caused very little damage on Jaluit and again its effects were confined to the islet of Jabor.

The Jaluit Project, a Trust Territory Agriculture Experiment Station, suffered the highest amount of damage and that was in plant loss. This damage was not great, however. During Typhoon MAMIE, U. S. Navy Sea Air Rescue Plane 909 on a sea rescue mission, was badly damaged at Jaluit.

Situation after Typhoon OPHELIA

On January 10, 1958, immediately after Typhoon OPHELIA struck Jaluit, the Island Development Officer was sent from the office of the District Administrator to survey conditions at Jaluit. OPHELIA struck Jaluit on January 7, 1958. Upon the arrival of the Island Development Officer at Jaluit, a report on conditions that existed was immediately forwarded to the District Center at Majuro. Immediate aid in the way of water, food, clothing and temporary shelters was brought in by the joint efforts of the Navy at Kwajalein and the Trust Territory.

The people had gone through a period of extreme physical hardship, but their mental attitude was quite healthy. They accepted the storm as something that happens and did not question why it had happened or how such storms occur. They were able to joke, sing and laugh, and accept the situation. They were ready to start rebuilding their homes with whatever material was available on the islands. They understood the scope of the problems before them, were cooperative and shared what little they had with others who were more unfortunate than they. There was no aimless wandering around as one might expect after such a devastating storm. Fourteen people were lost in the storm. (Two more died later.) Their loved ones showed some grief and sorrow, but accepted it as an act of God.

The survey of damage showed that the islets in the eastern part of the atoll suffered complete flood damage where three to eight foot waves of sea water had come over the islets. All houses and 95% of all trees were destroyed on the east coast. The majority of the cement cisterns were either destroyed or filled with salt water, creating an extreme shortage of drinking water. The west coast of Jaluit suffered approximately 60% damage to all trees and foliage. All of the sail boats which had been used to haul copra and passengers around the atoll were completely damaged or lost; fifty to sixty canoes were damaged beyond repair. It was impossible for people to move within the atoll. With the exception of the old concrete structures that were left by the Japanese, houses and other buildings in the atoll were destroyed.

Immediate aid was dispatched to the people of Jaluit by the U. S. Navy at the request of the District Administrator. A medical team was flown from Navy Station Kwajalein, 200 miles away, to examine the critically injured people and deliver additional medical supplies and food. Three injured people were flown to the Trust Territory Hospital at Majuro for surgery and hospitalization. An average of two flights a day came in with food, water and clothing. The Trust Territory vessel, M/V ROQUE, arrived five days later with additional food and water. On board were medical teams made up of two doctors, sanitarians, dental practitioners, health aides, the District Administrator, the Director of Agriculture and Fisheries, the Director of Coconut Operations and the Marshalls District Director of Public Health.

A complete survey was made of Jaluit, covering every phase of damage to the atoll. A program was put into effect immediately for the relief of the people at Jaluit. This involved movement of food, water, clothing, beddings and building material.

Adjustments in typhoon situations prior to American times

Spanish and pre-Spanish times

In the Marshall Islands after the Spanish claimed the islands in 1668 until 1885, there were no changes in the traditional rehabilitation methods following a typhoon. After a typhoon, the Marshallese were directed by their Iroij (King) with respect to the rehabilitation of the islands damaged by the storm. Food and tools were provided by the islanders in the atolls that were able to help. In many cases where

damage was to all of the islets in one atoll, the weak, the women and the children were moved to atolls close by. Food was brought from the neighboring atolls to help support the workers while they rehabilitated the atoll. At the completion of rehabilitation the majority of the workers were moved to join their families on one of the neighboring atolls. A very small group of workers were kept in the damaged atoll, where they maintained the plantings. When the first of the subsistence crops came into bearing, people slowly moved back into the islands. In many cases, a destructive typhoon was followed by a period of famine, sickness and great loss of life.

German times

During the occupation of the Marshalls by Germany, very little was done to help the people through typhoon rehabilitation. In 1905, Jaluit was struck by a typhoon that caused considerable damage to the northeastern side of the atoll. At the time of the storm, a German ship unloading cargo at Jabor, left to ride the storm out and returned to finish unloading. The food aboard the ship was the only food used to give temporary help and the Marshallese returned to the old system of rehabilitating themselves.

Japanese times

The Japanese, during their occupation of the Marshalls, carried out a program of rehabilitation of islands after any typhoon devastation. They usually helped the people struck by the storm with enough food to get them started on a rehabilitation program. They also sent in men to help them plan the replanting and feeding of the people. This program usually lasted about a year. No charge was made directly to the people, but a small tax was applied to the copra coming out of the atoll to cover the monies spent in helping with the rehabilitation.

Note: Attention should be directed to the beds of phosphatic hardpan (B-horizon) in the Jemo soil areas on Imroj and Kinajon (see p. 47) because of their potential economic value to the inhabitants as coconut plantations begin to show signs of phosphate deficiency. Analyses of samples of these phosphate rocks in the laboratories of the U. S. Geological Survey show 14 to 16% P_2O_5. While these small beds are insignificant commercially they should serve the needs of the local inhabitants for many years to come and render costly importation of commercial phosphates unnecessary. These beds are not, of course, in any way related to the typhoon under investigation, but their discovery by F. R. Fosberg was a valuable by-product of the expedition.--D.I.B.

GLOSSARY OF TERMS

Algal ridge. The relatively slight ridge, dominantly of calcareous algal composition, typically found at or near the edge of the reef flat on the ocean side.

Apron. See sand aprons.

Bar. Bar, spit, and hook are used in the usual sense. A bar is usually straight but may be curved or arcuate. An offshore bar is not tied to the land even at low-low tide. A spit or hook is a form of bar attached to the land, at least at low-low tide.

Beach rock. Rock formed from beach deposits, whether a beach sandstone or a beach conglomerate.

Boulder. A rock over 10 inches (25 cm.) in greatest diameter.

Boulder tracts or gravel tracts. Scattered patches or small fields of boulders or gravel lying on the reef flat.

Channel. See scour channel and surge channel.

Depression. See elongate depression and mangrove depression.

Elongate depression or longitudinal depression. Specifically, an elongated depression or trough between a bar, spit, or hook resting upon the reef flat and a shore ridge or shore slope that is part of an islet.

Erosion ramp. The gently sloping, relatively plane surface that lies just to landward of the reef flat, typically on the seaward sides of islets.

Foreslope. The steeply sloping surface between the reef margin and the deep ocean.

Gravel. An unconsolidated aggregate whose particles are dominantly larger than 2 mm. in diameter.

Gravel, small. An unconsolidated aggregate whose particles are dominantly between 2 and 100 mm. in diameter.

Gravel apron. See sand apron.

Gravel bar. See gravel and bar.

Gravel sheet. A gravel deposit in distinctly sheet form. More extensive in general than boulder tracts or gravel tracts (which see) and lying on an islet rather than on a reef flat.

Gravel tracts. See boulder tracts.

Hole. See plunge hole.

Hook. See bar.

Intertidal zone. The vertical zone between high-high and low-low tide levels.

Islet. An island of an atoll, most commonly upon the encircling reef but also one upon a pinnacle or reef patch in the lagoon.

Knoll. A coral growth comparable in size to a reef patch but rounded in aspect and whose summit is usually below low-low tide level.

Lime mud. Mud with calcium carbonate as a dominant constituent.

Longitudinal depression. See elongate depression.

Mangrove depression. A depression occupied by mangrove trees, but with a hard bottom rather than one comprised of muds or oozes, which is called a mangrove swamp.

Marsh. A depression containing grasses or sedges and with a mud or ooze bottom.

Muck. Mud that is dominantly organic.

Mud. Unconsolidated materials, sticky and cohesive when wet, whose particles are dominantly less than 1/32 mm. in diameter. See also lime mud.

Patches or patch reefs. Detached reefs, normally within the lagoon.

Pinnacle. A patch reef with a height greater than its maximum diameter.

Pit. See scour pit.

Plunge hole. A hole formed by running water on the downstream, down-slope side of a topographic break (steep slope).

Plunge pool. A deep plunge hole, approximately circular, containing water.

Ramp. See erosion ramp.

Reef. An eminence on the sea bottom rising to within 6 fathoms of the surface.

Reef flat. A relatively flat area of reef rock whose surface lies near low tide level.

Reef margin. The outer edge of the reef flat, usually marked by an abrupt change in slope.

Ridge. See algal ridge, also, shore ridge.

Rubble. Gravel of predominantly angular fragments.

Sand. An unconsolidated aggregate whose particles are dominantly between 1/32 and 2 mm. in diameter.

Sand apron or gravel apron. Apron-shaped deposits of sand or gravel, usually on lagoon reef flats.

Sand horn. A horn-shaped sand-bar typically found on the reef flat at the inner corner or end of an islet.

Scour channel. A channel across or partly across an islet, formed by the scouring action of water cutting through unconsolidated or consolidated material that lies above the reef flat.

Scour pit. A depression formed by running water on the downstream side of an obstruction, such as an uprooted palm.

Shore ridge. A ridge upon or immediately adjacent to a shore. (Also called beach ridge.)

Spit. See bar.

Submarine terrace. The relatively flat, almost horizontal surface sometimes found at depth on the ocean side of the foreslope.

Surge channel. A channelway in the reef, typically normal to and across the reef margin and foreslope on the ocean side.

Swamp. A depression containing woody plants and with a mud or ooze bottom. See also mangrove depression and marsh.

Terrace. See submarine terrace.

Typhoon. A storm that forms over the tropical oceans and has sustained windspeeds greater than 73 m.p.h. (Same as hurricane.)

Woodland. An open stand of trees.

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APPENDIX I.

TABLE OF PLANT SPECIES BY ISLETS

F. R. Fosberg

The following table includes recent reports (from 1946 on) of species known from Jaluit by islets, the 8 islets listed being the ones definitely examined since 1946. There are various additional earlier records of plants from the atoll, but mostly without record as to the islet where they occurred.

Added in the last two columns are indications of origin and of growth habit.

Sources		Origin		Habit	
Fosberg	F	Native	I	Epiphytic herb	E
Mackenzie	M	Aboriginal introduction	A	Terrestrial erect herb	H
St. John	S	Naturalized	N	Creeper	C
Lyman	L	Cultivated or persisting from cultivation	C	Climber	V
Unverified but probably present	X			Shrub	S
				Tree	T
				Seedling	(s)

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON after typhoon	MAJURIREK after typhoon	PINLEP after typhoon	RIBON after typhoon	LIJERON after typhoon	Origin	Habit
Asplenium nidus	X	F	FS	F	X	F	F	F	F	F	F	I	EH
Nephrolepis acutifolia			FS	F	X	F	F	F		F		I	E
Nephrolepis biserrata var. furcans	M											C	H
Nephrolepis hirsutula			FS	F			F	F	F			I	H
Polypodium scolopendria			FS	F	X	F	F	F	F	F		I	ECH
Pteris tripartita			FS					F	F			I	H
Vittaria incurvata			FS					F		F		I	E
Cycas circinalis	L	F										C	ST
Pandanus tectorius	M	F	FS	F	F	F	F	F	F	F		CIA	T
Thalassia hemprichii									F			I	C
Cenchrus echinatus	F	F		F					F			N	H
Cynodon dactylon								F				N	C
Digitaria pruriens var. microbachne	F	F	S	F		F	F	F	F			I?	H
Echinochloa crus-galli									F			N?	H
Eleusine indica	F	F	S	F		F	F	F	F			N	H
Eragrostis amabilis	F	F	S	F			F	F	F			N	H
Lepturus repens vars.	F	F	X	F	X	F	F	F	F	F	F	I	HC
Paspalum conjugatum									F			N	HC

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON	MAJURIREK	PINLEP	RIBON	LIJERON	Origin	Habit
							after typhoon	after typhoon	after typhoon	after typhoon	after typhoon		
Paspalum distichum		F										N	HC
Sorghum bicolor	F	F	S									N	H
Thuarea involuta	F	F	SX	F	X	F	F	F	F			I	C
Cyperus alternifolius	M											C	H
Cyperus compressus		F										N	H
Cyperus javanicus	F	F					F		F			I	H
Cyperus kyllingia	F	F										N	H
Cyperus odoratus									F			I	H
Cyperus rotundus	X	F										N	H
Eleocharis geniculata									F			IA	H
Fimbristylis cymosa	F	F	XS	F	X	F	F	F	F			I	H
Cocos nucifera	F	F	XS	F	X	F	F	F	F	F	F	AC	T
Elais guineenis	M											C	T
Phoenix canariensis?	M											C	T
Pritchardia pacifica	M											C	T
Alocasia macrorrhiza	M	F	FS	F	X	F	F	F	F			A	H
Colocasia esculenta		F							F			AC	H
Cyrtosperma chamissonis			S						F			AC	H
Epipremnum pinnatum	M	F										N	V
Scindapsus aureus	L	F										N	V

Plants	JABOR & SYDNEYTOWN		IMROJ		MEJATTO		KINAJON	MAJURIREK	PINLEP	RIBON	LIJERON	Origin	Habit
	before typhoon	after typhoon	before typhoon	after typhoon	before typhoon	after typhoon	after typhoon						
Xanthosoma sagittifolia	X	F	F					F				C	H
Rhoeo spathacea	M	F										C	H
Agave sisalana	X	F										C	H
Cordyline terminalis	L	F										C	S
Sansevieria roxburghii?	L	F										C	H
Crinum asiaticum?	M	F	FS	F	F	F	F	F	F			CA	H
Hippeastrum puniceum				F				F				C	H
Hymenocallis littoralis	M	F	F					F	F			C	H
Zephyranthes rosea	X	F	X	F			F	F				C	H
Dioscorea sp.			S									A	V
Tacca leontopeta-loides	M		FS	F	X	F	F	F	F			A	H
Musa nana			S		F			?				C	H
Musa sapientum	M	F	S	F	F		F					C	H
Canna indica?	L							?				C	H
Peperomia pellucida	X	F										N	H
Peperomia ponapensis			F					F				I	H
Casuarina equisetifolia	L	F										C	T
Artocarpus altilis (incl. A. mariannensis)	F	F	FS	F	F	F	F	F	F			AC	T
Ficus elastica	F	F										C	T
Ficus tinctoria	X	F										C	T

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON after typhoon	MAJURIREK after typhoon	PINLEP after typhoon	RIBON after typhoon	LIJERON	Origin	Habit
Fleurya ruderalis	F	F	F	F	X	F	F	F	F	F		I	H
Pilea microphylla	F	F	S				F					N	H
Pipturus argenteus			FS	F(s)	X	F	F	F	F			I	ST
Procris pedunculata								F				I	HE
Coccoloba uvifera	M											C	S
Boerhavia tetrandra								F				I	C
Bougainvillea glabra	M											C	V
Bougainvillea spectabilis	M						?					C	V
Mirabilis jalapa		F	FS	F				F				CN	H
Pisonia grandis			FS		X	F		F	F	F	F	I	T
Amaranthus viridis		F					F					N	H
Celosia argentea			FS									C	H
Gomphrena globosa		F						F				C	H
Portulaca oleracea	F	F		F		F	F	F				N	H
Cassytha filiformis			F	F			F	F	F			I	VC
Hernandia sonora	X	F		F	F			F				I	T
Brassica acanthiformis	M											C	H
Nasturtium sarmentosum		F										I?N	H
Kalanchoe pinnata			FS	F			F					N	H
Albizia lebbek	M											C	T

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON (after typhoon)	MAJURIREK (after typhoon)	PINLEP (after typhoon)	RIBON (after typhoon)	LIJERON (after typhoon)	Origin	Habit
Canavalia microcarpa	F					F	F	F		F(s)	F(s)	I	V
Caesalpinia pulcherrima			FS									C	S
Cassia occidentalis		F										C	H
Crotalaria incana	F	F										N	H
Delonix regia	M	F										C	T
Erythrina variegata var. orientalis	M	F										C	T
Inocarpus fagiferus	M	F										C	T
Intsia bijuga					F	F	F	F			F	I	T
Leucaena glauca	L	F						?				N	S
Samanea saman	X	X										C	T
Sophora tomentosa					F							I	S
Vigna marina	X	F	FS	F		F	F	F	F	F(s)	F(s)	I	CV
Citrus aurantifolia	M	F						F	F			C	S
Citrus maxima	M											C	S
Citrus sinensis	M	M										C	S
Citrus reticulata	M											C	S
Acalypha wilkesiana	M	F							F			C	S
Codiaeum variegatum								F				C	S
Euphorbia chamissonis								F	F			I	H
Euphorbia glomerifera	F	F										N	C

Plants	JABOR & SYDNEYTOWN		IMROJ		MEJATTO		KINAJON	MAJURIREK	PINLEP	RIBON	LIJERON	Origin	Habit
	before typhoon	after typhoon	before typhoon	after typhoon	before typhoon	after typhoon	after typhoon						
Euphorbia hirta	F	F					F		F			N	H
Euphorbia prostrata		F							F			N	C
Euphorbia pulcherrima	M											C	S
Phyllanthus amarus	F	F					F		F			N	C
Ricinus communis	M											C	S
Allophylus timorensis	F		S		F		F	F	F			I	ST
Triumfetta procumbens	F		FS	F		F	F	F	F	F(s)		I	C
Hibiscus esculentus	M	F										C	H
Hibiscus mutabilis	M											C	S
Hibiscus tiliaceus	X	F	FS				F		F			IA	ST
Sida fallax					F							C	S
Thespesia populnea	M											C	T
Bombax ellipticum	M											C	T
Ceiba pentandra	M	F	F									C	T
Calophyllum inophyllum	X	F	FS	F	F	F	F	F	F		F(s)	A	T
Passiflora laurifolia	M											C	V
Carica papaya	M	F	FS	F			F	F	F			CN	ST
Citrullus vulgaris	M											C	C
Cucumis sativus	M											C	C
Cucurbita maxima	F?	F		F?				F?	F			C	C
Cucurbita pepo	M		S									C	C

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON	MAJURIREK	PINLEP	RIBON	LIJERON	Origin	Habit
							after typhoon						
Pemphis acidula	F	F			X	F		F		F	F	I	ST
Sonneratia alba	F											I	T
Bruguiera gymnorhiza	F		F	F	X	F	F	F	F			I	T
Lumnitzera littorea			F									I	T
Terminalia catappa	M	F			X	F						A	T
Terminalia samoensis			FS		X	F		F	F	F	F	I	S
Barringtonia asiatica			FS	F	X	F				F(s)	F(s)	I	T
Miconia sp.?	M											C	S
Brassaia actinophylla	M	F										C	T
Polyscias fruticosa	M											C	S
Polyscias guilfoylei	L		S									C	S
Polyscias scutellaria			S					F				C	S
Polyscias tricochleata									F			C	S
Centella asiatica			FS	F				F	F			A	C
Jasminum sambac								F				C	S
Catharanthus roseus									F			C	H
Cerbera manghas	M	F										C	T
Nerium indicum					F			?				C	S
Nerium oleander			F					?				C	S
Ochrosia oppositifolia			F	F								I	T
Plumeria rubra	M		FS			F	F	F	F			C	ST

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON after typhoon	MAJURIREK after typhoon	PINLEP after typhoon	RIBON after typhoon	LIJERON after typhoon	Origin	Habit
Asclepias curassavica			F						F			C	H
Ipomoea batatas			F									C	C
Ipomoea littoralis		F	FS						F			I	C
Ipomoea pes-caprae	F	F								F(s)		NI?	C
Ipomoea tuba	F	F	S				F					I	C
Cordia subcordata	F	F	FS	F				F	F	F	F	I	T
Tournefortia argentea	F	F	XS	F	X	F	F	F	F	F	F	I	TS
Clerodendrum inerme	X	F	F	F				F				I	S
Lantana camara	M											C	S
Premna obtusifolia	X	F	F	F	F	F		F				I	T
Stachytarpheta urticifolia	F	F										N	H
Ocimum sanctum			FS						F			AC	H
Nicotiana tabacum	F		S									C	H
Physalis angulata	F	F				F	F	F	F			N	H
Solanum nigrum		F							F			N	H
Jacaranda filicifolia	M											C	T
Beloperone guttata	M											C	S
Blechum brownei	F	F										N	H
Hemigraphis reptans									F			N	C
Pseuderanthemum carruthersii v. carruthersii	X	F			F	F		F				C	S

Plants	JABOR & SYDNEYTOWN before typhoon	JABOR & SYDNEYTOWN after typhoon	IMROJ before typhoon	IMROJ after typhoon	MEJATTO before typhoon	MEJATTO after typhoon	KINAJON after typhoon	MAJURIREK after typhoon	PINLEP after typhoon	RIBON after typhoon	LIJERON after typhoon	Origin	Habit
Pseuderanthemum carruthersii v. atropurpureum	X	F	FS	F	X	F	F		F			C	S
Dentella repens	M	F										N	C
Guettarda speciosa	F		XS	F	X	F	F	F	F	F	F	I	T
Hedyotis biflora		F	FS	F	F							IN	C
Ixora casei			S									C	S
Ixora fraseri	M											C	S
Morinda citrifolia	F	F	XS		X	F	F	F	F	F		I	ST
Hippobroma longiflora		F										N	H
Scaevola sericea	F	F	XS	F		F		F	F	F		I	S
Adenostemma lavenia			FS				F					A	H
Ageratum conyzoides		F										N	H
Cichorium endivium	M											C	H
Spilanthes iabadicensis	M											N	H
Synedrella nodiflora		F					F		F			N	H
Tagetes sp.								F				C	H
Vernonia cinerea		F	FS			F		F	F			N	H
Wedelia biflora	F	F	XS	F	X	F	F	F	F	F		I	CHV

APPENDIX II

GASTROPOD MULLUSCS COLLECTED BY J. L. GRESSITT

List prepared by Yoshio Kondo

Marine species

Turbinidae : Turbo argyrostomus L.? --Mejatto (2 specimens).

Neritidae : Nerita plicata L. --Mejatto (1 spm.).

Nassariidae : Nassarius cf. papillosus L. --Mejatto.

Planaxidae : Planaxis sulcatus Born ? --Lijeron

Land species

Realidae : Omphalotropis fragilis Pease --Imroj (1 dead); Jabor (1 dead juvenile, probably this sp., Bernese funnel from Pandanus).

Assimineidae : Assiminea nitida Pease --Jabor (1 dead, Berlese funnel from Pandanus); Imroj (2 dead).

Truncatellidae : Truncatella guerini Villa --Jabor (16 live; 1 dead juvenile in Berlese funnel may be this sp.); Imroj (4 dead).

Melaniidae : Melania sp. --Pinlep (5 dead; fresh or brackish water).

Ellobiidae : Melampus luteus Quoy & Gaimard --Imroj (2 dead; littoral).

Tornatellinidae : Tornatellinops variabilis Odhner --Kinajon (about 150 live and 3 dead)

Pupillidae : Gastrocopta pediculus Shuttleworth --Jabor (1 dead, Bernese funnel from Pandanus); Imroj (1 dead).

Stenogyridae : Lamellaxis oparanum Pfeiffer --Jabor (1 dead).

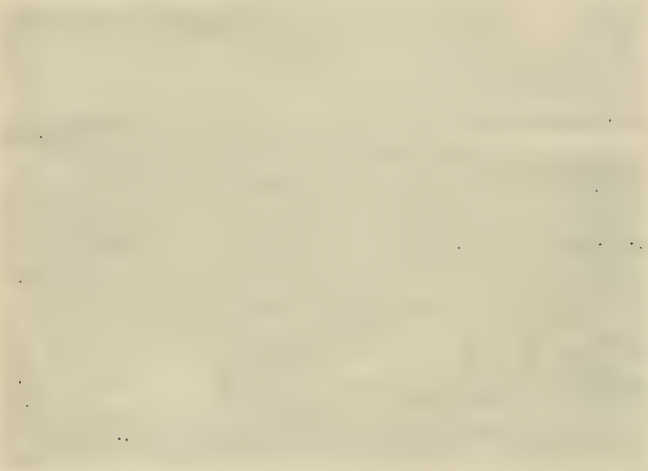
Zonitidae : Liardetia sp.? --Jabor (1 dead juvenile, obtained from Berlese funnel, in Pandanus).

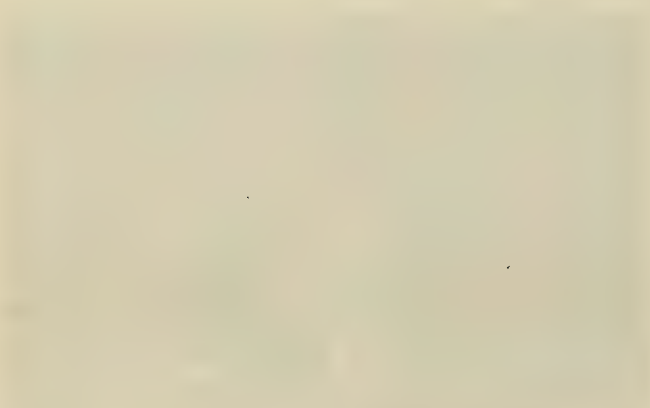
a. Ridge of boulder gravel thrown up on reef flat. Jabor I. (Fosberg photo).

b. Same ridge, close-up showing imbrication of slab-like boulders of coral, principally Acropora sp. (Fosberg photo).

c. Aerial view of Sydneytown area showing large tank surrounded by rubble embankment covered by vegetation and two smaller tanks which have been moved by the storm waves from the two circular foundations visible just beyond the farther tank. Scour channel across reef to left of nearer small tank. (Gressitt photo).

d. Large boulder resting on lagoon bar, Jaluit Islet, 3000 feet north of Blockhouse No. 4. The white upper half and stained lower half suggest that it has been overturned, that the white half was previously buried, the stained half exposed. The board leaning against it is 2 feet long. (Wiens photo).





a. Eroded beach rock ridge with depression landward of it, boulder gravel ridge on reef in background, Jaluit Islet south of Jabor. (Wiens photo).

b. Scour channel cut through about 4 feet of conglomerate rock, displaced tank and typhoon-battered vegetation in background; near Sydney-town. (Wiens photo).

c. Scour pit, showing extensive exposure of root systems, battered Pandanus and coconut trees, gravel sheet in background, some original soil surface in right foreground; Mejatto, south of "Station 4". (Wiens photo).

d. Root masses of coconut and Pandanus trees; the height of these (about 5 feet) suggests that a very substantial thickness of soil has been scoured away in the foreground; about 3000 feet from north end of Mejatto. (Wiens photo).

Plate II

a. Pemphis partly washed out and partly buried by gravel sheet; Jaluit I. about 1000 feet north of steel towers. (Wiens photo).

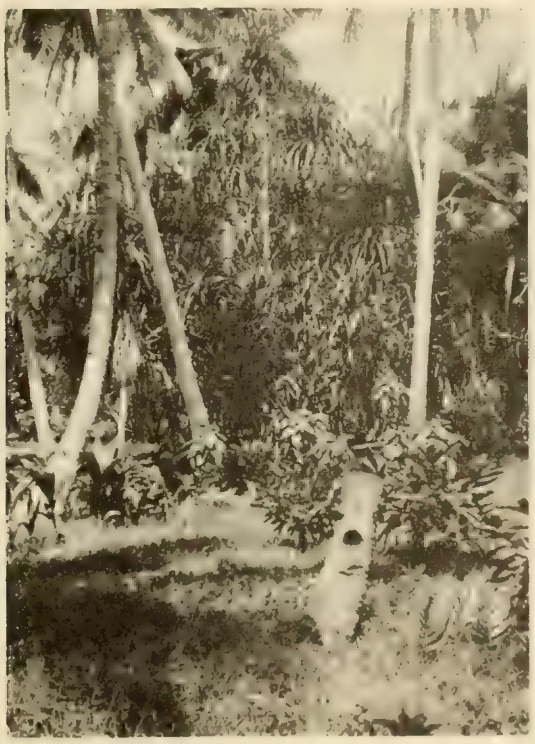
b. Lagoonward front of gravel sheet; just south of Jabor. (Wiens photo).

c. Lagoonward front of gravel sheet encroaching on small mangrove depression and partly filling it in; Mejatto I. (Wiens photo).

d. Another such depression, partly filled by gravel sheet; Mejatto I. (Wiens photo).

a. Path in coconut-breadfruit plantation before typhoon OPHELIA; Mejatto I. (Fosberg photo, 1946).

b. Opening in coconut-breadfruit plantation, breadfruit tree in center, before typhoon OPHELIA; Mejatto I. (Fosberg photo, 1946).



c. Opening in coconut plantation, Pandanus tree in center; Mejatto I. (Fosberg photo, 1946).

d. Mangrove depression, partly cleared by typhoon OPHELIA, showing Bruguiera trees bare of leaves above, accumulated vegetable debris in foreground; Mejatto I. (Fosberg photo).

Plate IV

a. Marshallese thatched house, surrounded by Pandanus trees, before typhoon OPHELIA; Mejatto I. (Fosberg photo, 1946).

b. Area with vegetation and loose material completely scoured off; South of Jabor. (Fosberg photo).

c. Trash thrown into mangrove depression; Bruguiera in background beaten down; Mejatto I. (Fosberg photo).

d. Coconut trees snapped off by typhoon OPHELIA; Mejatto I. (Fosberg photo).

a. Uprooted breadfruit and coconut trees, broken Pandanus, battered coconut plantation. (Gressitt photo).

b. Partially uprooted young coconut tree and snapped coconut trunk in destroyed coconut plantation. (Gressitt photo).

c. Battered but still standing Barringtonia (?), Pandanus, and coconut trees, snapped off coconut trunks. (Gressitt photo).

d. Vegetable debris on wave-swept ground, north of Sydneytown; old tank in background. (Gressitt photo).

a. Coconut and Pandanus root systems exposed by removal of soil, base of snapped-off Pandanus and snapped off coconut trunks in battered coconut plantation. (Gressitt photo).

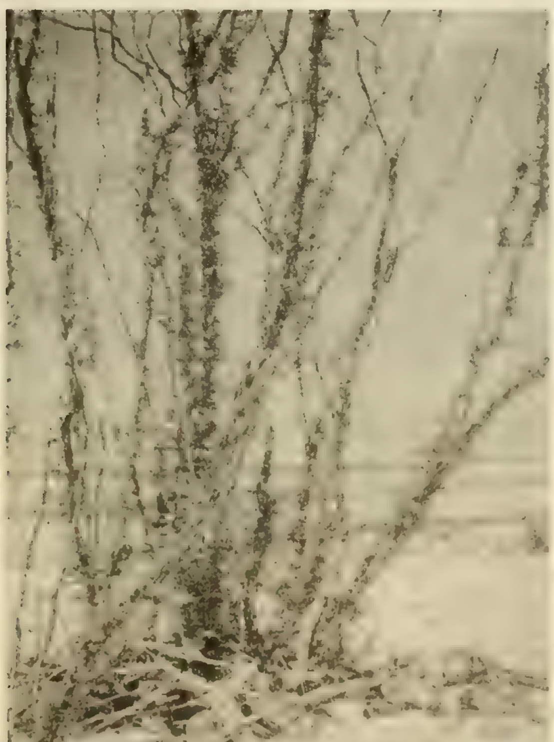
b. Partially buried vegetation, broken Pandanus and other trees, battered coconut plantation. (Gressitt photo).

c. Coconut trunks fallen in several directions; Imroj I. (Fosberg photo).

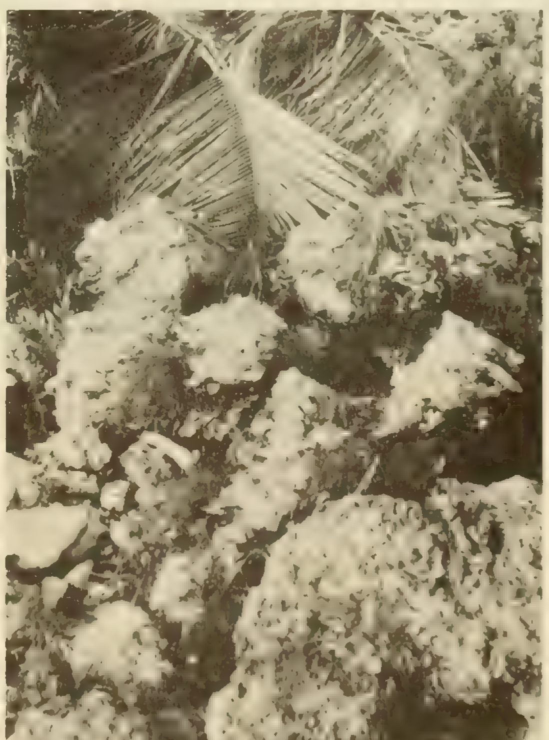
d. Area hit by wind only, showing broken Pandanus and coconut trees, but relatively undisturbed ground vegetation; Pinlep I. (Fosberg photo).

a. Breadfruit tree damaged by wind, broken Pandanus and coconut trees in background, relatively undamaged ground vegetation, area affected by wind only; southeast end of Imroj I. (Fosberg photo).

b. Breadfruit tree with branches stripped off by wind, sending out sprouts with new leaves, ground vegetation of Wedelia favored by increased sun light resulting from typhoon damage to other vegetation, area not inundated; Pinlep I. (Fosberg photo).



c. Pemphis clump with small branches stripped off but sprouting abundant new twigs and leaves; just south of Jabor. (Wiens photo).



d. Phosphate boulders, part of bed discovered during this investigation; northwest end of Imroj I. (Fosberg photo).

Plate VIII

a. Broken off Pemphis bushes on conglomerate platform on lagoon shore south of Sydney-town. (Fosberg photo).

b. Taro pit, with Cyrtosperma tops killed by typhoon but otherwise not seriously damaged; Pinlep I. (Fosberg photo).

c. Coconut plantation in uninundated area, showing damage by wind alone; Pinlep I. (Fosberg photo).

d. Coconut plantation damaged by wind and waves, many trees snapped off, some uprooted, root systems exposed, gravel deposited on soil; showing Marshallese inhabitants. (Gressitt photo).

Plate IX

a. Coconut plantation destroyed by wind and waves; Mejatto I. (Wiens photo).

b. Inner margin of fresh gravel sheet; Mejatto I. (Fosberg photo).

c. Pandanus grove destroyed by wind; Majurirek I. (Fosberg photo).

d. Pisonia forest battered by wind, but sprouting vigorously; Lijeron I. (Fosberg photo).

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It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs during the past fourteen years.

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Correspondence concerning the Atoll Research Bulletin should be addressed to the above

c/o Pacific Vegetation Project
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No. 76

Observations on Puluwat and Gaferut, Caroline Islands

by

William A. Niering

with

Historical and climatic information on Gaferut Island
by Marie-Hélène Sachet

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William A. Niering*

Introduction

Observations presented in this paper were made during the summer of 1954 in conjunction with the Kapingamarangi Expedition to the Caroline Islands**. On the return route to Guam, several other island groups were visited for purposes of comparison. Among these were Puluwat and Gaferut.

I. List of plants noted on Puluwat Islet, Puluwat Atoll

The following species were recorded during a one-hour visit to the islet on Sept. 3, 1954.

Allophylus timorensis Bl.
Occasional in undergrowth.

Artocarpus altilis (Park.) Fosb.
Scattered in interior. Coll. no. 765.

Asplenium nidus L.
Women observed carrying leaves, growing plants not seen.

Calophyllum inophyllum L.
Large trees along lagoon shore.

Canavalia sericea Gray
Frequent in forested and semi-open areas. Coll. no. 769.

Carica papaya L.
Frequent around houses.

Cassytha filiformis L.
Occasional on undergrowth

Cocos nucifera L.
Trees scattered forming open plantations, also young plantings.

Colocasia esculenta (L.) Schott
Important food species.

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* Department of Botany, Connecticut College, New London, Connecticut.

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Cordia subcordata Lam.
Large specimens along lagoon beach.

Crinum sp.
Profusely flowering along paths.

Cucurbita sp.
Large productive squash in living area.

Eleusine indica (L.) Gaertn.
Frequent in open disturbed sites. Coll. no. 771.

Euphorbia chamissonis Boiss.
Occasional along sandy lagoon beach. Coll. no. 770.

Ficus prolixa Forst.
Coll. no. 767.

F. tinctoria var. *neo-ebudarum* (Summ.) Fosb.
Coll. no. 766.

Guettarda speciosa L.
Occasional in interior.

Hedyotis biflora (L.) Lam.
Coll. no. 762.

Hibiscus tiliaceus L.
Occasional in understory.

Hymenocallis littoralis (Jacq.) Salisb.
Coll. no. 772.

Ixora sp.
Red flowered ornamental around houses.

Lepturus repens R. Br.
Occasional in disturbed sandy areas.

Messerschmidia argentea (L.f.) Johnst.
Mixed with *Scaevola* along ocean beach.

Morinda citrifolia L.
Occasional as understory tree.

Musa sp.
Frequent around houses.

Nephrolepis hirsutula (Forst.) Presl
Dominant fern in coconut plantations often forming a dense ground cover 2-3 feet high.

Pandanus tectorius Park.
Frequent, often more common oceanward.

Paspalum conjugatum Berg.
Occasional in open disturbed areas. Coll. no. 763.

Piper betle L.?
Coll. no. 768.

P. fragile Benth.?
Coll. no. 764.

Plumeria rubra L.
Occasional in living area.

Polypodium scolopendria Burm. f.
Frequent on trees, often associated with Nephrolepis.

Portulaca sp.
Yellow flowering form, frequent along and in paths.

Premna obtusifolia R. Br.
Dominant in undergrowth.

Scaevola sericea Vahl
Frequent as a border along beaches.

Stenotaphrum micranthum (Desv.) Hubb.
Frequent in recently cleared areas planted to coconut.

Thalassia hemprichii (Ehrb.) Aschers.
Frequent in shallow sandy lagoon waters.

Thuarea involuta (Forst.) R. & S.
Frequent in recently cleared areas planted to coconut.

Triumfetta procumbens Forst.
Occasional along ocean beach.

Vernonia cinerea (L.) Less.
Weed of open areas.

Wedelia biflora (L.) DC.
Frequent in undergrowth.

Mangrove
Present along south lagoon cove (genus not determined).

II. Description of Gaferut Island

Gaferut Island, an isolated land mass in the northern Carolines, was observed during a brief stop on the morning of Sept. 4, 1954*. The island is approximately 1,500 feet long and 500 feet wide, situated on a somewhat crescent-shaped reef which extends 500-750 feet outward from mean tide level. Gaferut is at present uninhabited, but the Japanese mined phosphatic rock there around 1935. Remnants of their buildings, clearings and excavations can still be seen. About an acre in the interior, although now overgrown, shows evidence of being cleared. In at least four areas excavations were observed, the most extensive being a trench about 2 feet in depth and of considerable width. The other areas within the clearing were quite small.

Geology and Soils

Geologically the island is composed of three types of material: phosphatic rock, coral rubble and sand. The higher interior portion is underlain by phosphatic rock which gives way to a marginal coral rubble border 100 feet or more in width on the east and southeast sides. Along the western shoreline high step-like beach ridges composed of rubble extend 6 feet or more above mean tide level. The sandy deposits form a conspicuous elongated bar extending in a northwesterly direction. Near the end of the sand bar is a very large coral boulder which was probably perched there during a severe storm. These various areas are readily discernable on the aerial photograph (Fig. 1).

The interior phosphatic rock is either exposed, except for blackish algal or fecal coverings, or overlain with a thin rubble soil or humus layer. Several inches of rubble mixed with organic matter are typical. However, in the largest clearing rubble is absent and the rock is overlain by a dark brown friable acid humus (pH 5) varying from 2 to 3 inches in depth. In one area within but near the edge of the clearing it was found to a depth of 6 to 8 inches. These variations in depth may be correlated with the disturbance. One sample from this area contained large quantities of small gastropod shells. Beneath the humus the underlying rock consisted of cemented coral fragments, sand and foraminiferal tests, whereas those from the trench consisted primarily of larger rubble. In both cases the material was similar in that it exhibited a brownish salt and pepper appearance and was relatively soft so that it could be easily broken with one's fingers. In the trench the rock was exposed for at least 2 feet in depth with no evidence of an unconsolidated layer beneath. The humus layer and underlying phosphatic rock have all the characteristics of the Jemo Series named and described by Fosberg (1954) and observed by other investigators (Hatheway 1953, Niering 1956, McKee 1956). Further discussion concerning the possible origin of the rock will follow in a later section.

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Vegetation and Associated Animal Life

The general vegetational aspect is that of a low, relatively open forest, 12 to 25 feet in height. The dominant tree which characterizes the island is Tournefortia argentea, rather than the coconut which is so typical of inhabited islands. Only two mature coconut trees (Cocos nucifera) 50 to 60 feet in height, probably planted within the last 10 years, were found. The only other woody plant observed was Caesalpinia sp., and it was unimportant. On the phosphatic rock of the interior which has been least disturbed the trees are relatively large and frequently form a continuous but open canopy, in contrast to the marginal rubble borders where the trees are smaller and more scattered. On this coarse marginal rubble the Tournefortia frequently exhibit a shrubby dome-like appearance with branches extending to the ground. In the rubble areas the trees reach 6 to 10 inches in diameter and in the interior sections attain diameters of 12 to 18 inches. The dominant ground cover is Fleurya ruderalis which forms a continuous layer 12 to 18 inches in height in the openings and decreases slightly in the semi-open situations. Several specimens of a cucurbit (Cucurbita sp.) also occurred locally.

Associated with the Tournefortia community is a large bird population including frigate birds (Fregata minor palmerstoni), red footed boobies (Sula sula rubripes), and white terns (Gygis alba candida). Of these the frigate birds are most abundant. Their nests and immature specimens were conspicuous in the trees. At all times the air was filled with the din of hundreds of birds in constant flight. From a kodachrome taken over the island an estimated 550 birds were counted. While walking through the interior one had to be careful of these large birds since one could easily have been hit as they lost altitude on the take-off. Under those trees with many nests the stench was very pronounced and the absence of Fleurya may be correlated with the concentration of guano. It was truly amazing to see such great numbers of birds but presumably this is not atypical of certain uninhabited islands. Pokak, an uninhabited atoll in the Marshalls, is quite similar not only in its large bird population but also in its sparse flora (Fosberg 1957). Here 9 species of vascular plants were found in contrast to 7 on Gaferut.

Associated with the coconut were azure-tailed skinks (Emoia cyanura cyanura) and coconut crabs (Birgus latro). The former were especially abundant in the trees; the latter were found under the fronds on the ground as well as within the nearby herbaceous cover. The largest crabs, one foot or longer, were in the cavities of the rock. Although ten nuts had sprouted under the trees they were partly chewed and the 1 to 2 foot shoots were badly damaged. Whether they will survive is questionable. Other animal life observed included hermit crabs and in the branches of the Tournefortia orb-weaving spiders were common.

In the large clearing toward the south end of the island dense growths of Ipomoea tuba cover most of the opening and are invading the surrounding Tournefortia and forming a complete covering over the trees. Several have already been killed as a result of this invasion. Infesting this viny growth was a caterpillar which develops into a whitish Lepidopteran. Leaves not damaged by this infestation were difficult to find. Another herb found locally in the clearing was Boerhavia diffusa, both the pink and white forms.

At the north end of the island most of the sand bar is devoid of vegetation. However, small *Tournefortia* are becoming conspicuously established at the south end of the bar. In this sector sea turtle activity was evidenced by the many excavations in the exposed beach sand. Also along the shore a flock of 12 to 15 turnstones (*Arenaria interpres interpres*) were seen as well as several plovers in flight.

Discussion

The origin of the phosphatic rock is of considerable interest in that it resembles the Jemo Series. The A (humus) and B (rock layer) horizons are comparable but the less consolidated C horizon was not found. Although the greatest depth reported elsewhere for the cemented B layer is $1\frac{1}{2}$ feet, from Jemo Island, this may merely indicate that cementation on Gaferut has taken place to a greater depth. To be associated with the Jemo Series infers a dual biotic relationship only one component of which currently exists on Gaferut - namely, a large bird population. The other facet - a *Pisonia* forest, is wanting. Could there have been a *Pisonia* forest in the past - the soil forming processes operative for a long period resulting in the formation of the phosphatic rock and then the forest destroyed by a typhoon? (See section on climate below). Denudation of islands resulting from typhoons has also been reported from Ailinginae and Utirik Atolls in the northern Marshalls (Fosberg 1956) and most recently by Blumenstock (1958) and Fosberg (1961) on Jaluit Atoll in the Marshalls. The small very intensive typhoon which hit Jaluit completely removed the vegetation on the narrower parts of certain islets. Many trees were uprooted or snapped off and washed away. Large *Pisonia* trees were uprooted, and others still standing had many branches blown off and were greatly defoliated. During the height of the storm wave surges 6 feet in height and locally more than 8 feet swept over the islets accompanied by winds approaching 125 knots (Blumenstock 1958). From these observations it is not unreasonable to assume that a *Pisonia* forest could have been destroyed on Gaferut (see note on p.13). Surely the very soft nature of the wood would lend itself to tremendous storm damage. Although persisting root systems would tend to produce vigorous root suckers prolonged salt water inundation might well have killed any remaining root systems which were not completely washed away. A small isolated island such as this one would be particularly vulnerable to heavy damage since it would get the full impact of the storm regardless of the direction from which it came. That a severe storm has hit Gaferut is evidenced by a large coral boulder off the north end of the island. Wiens (1959) observed large blocks of this type on Jaluit which were washed 100-300 feet during the typhoon. In addition, the extensively developed marginal rubble border along the east and south sides of the island and the high beach ridges on the west may well have been laid down during such a storm. The fact that phosphatic rock formation does not appear to be occurring at present and has never been reported under *Tournefortia* suggests that it occurred under a different vegetation type presumably *Pisonia grandis*.

Although the idea that a severe storm may have destroyed the *Pisonia* forest is most tenable, its removal by man in clearing the land to facilitate the mining of phosphate is another possibility.

Deleterious effects of the existing bird population were not strikingly evident as has been observed by Hatheway (1955) on Canton Island, where he found dead and dying Tournefortia, presumably associated with the concentrated guano deposits; this is probably correlated with the drier climate of Canton Island in contrast to Gaferut. On Gaferut the larger trees heavily used by birds were not as vigorous in appearance as those in other areas but no dead trees were noted resulting from this factor. However, as mentioned above, the sparsity of herbaceous cover and seedling reproduction may be correlated with excessive guano. Periodic visits by natives may also play some role in reducing the bird population, but their present density would suggest that this influence is negligible.

In interpreting future trends within the existing vegetation it appears that Tournefortia will probably persist as the typical vegetation for some time since there are no other competitive species available which might replace it such as Pisonia or Ochrosia oppositifolia. Whether or not adequate reproduction will occur to replace mature trees in the future is questionable at this point. The two coconut palms that were presumably planted do not appear to be spreading. In fact, the poor vigor of the sprouted nuts as a result of coconut crab activity would suggest that the palm will probably not become an important part of the vegetation. This may well be a limiting factor in the establishment of coconut, even if introduced, on uninhabited islands or those where the coconut crab population is not kept in check. Since the crab is considered such a delicacy by the natives it presents no serious threat on inhabited islands. Another species, Ipomoea tuba, must also be considered since it has already engulfed and killed several Tournefortia. It is not impossible to visualize this very aggressive and drought-resistant species as eventually becoming dominant over an increasingly extensive portion of the interior.

Summary

1. Gaferut, an uninhabited island in the northern Carolines, is dominated by a low forest of Tournefortia argentea. Associated with this community is a large bird population, primarily frigate birds and red footed boobies.

2. The underlying phosphatic rock resembles that of the Jemo Series. Its presence suggests that formerly a Pisonia forest existed on the island and has since been destroyed perhaps by a typhoon. A large coral boulder perched on the reef is indicative of a severe storm in the past.

3. Tournefortia will probably persist as the dominant vegetation for some time. The coconut palms, presumably planted, do not appear to be spreading. Ipomoea tuba which has already killed several Tournefortia may become increasingly important in the future.

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Fig. 1 Aerial view of Gaferut Island taken April 1944, 10 years prior to the present observations. Light gray vegetation dominant throughout is *Tournefortia argentea*. Rubble areas are evident, demarcated by the scattered specimens of *Tournefortia*, especially on the eastern and southern sides. On the phosphatic rock of the interior, *Tournefortia* forms a somewhat circular pattern around a uniform darker area which represents the section cleared for phosphate digging. In 1954 the cleared area was dominated by *Ipomoea tuba*. The sand bar building northwestward is devoid of vegetation. If the coconuts were present at the time the photo was taken, they were too small to be detected. There appears to have been relatively little change in the vegetational pattern in the 10 year period.

Photo courtesy of U. S. Navy.

Historical and climatic information on Gaferut Island

by

Marie-Hélène Sachet

In view of the scarcity of information on Gaferut, it seemed worthwhile to utilize the library resources of Washington in order to supplement the valuable observations made by Dr. Niering.

History

The real native name of Gaferut is Faiau, Fallao (Spanish spelling), or Fayo (which means stone or rock in the Woleai language of nearby islands). The name Gaferut is never included in the old lists of islands of the Carolines, and, according to Smith (1951, p. 30), is never used by local people. Chamisso (1821, p. 115) relates how Carolinians from Woleai, Lamotrek and other atolls went every spring (April) to Guam, stopping on the way for several days at "Fayo, the desert island," and returning in May or June by the same route. Riesenberg and Kaneshiro(1960, p. 285) identify this stopping place as Gaferut. Chamisso also discusses some of the early descriptions of these central Caroline atolls and includes a chart modified from Cantova (1728), in which our Gaferut is obviously the island called Fauheu.

Of this island, Chamisso says also (p. 124) that it is uninhabited, without fruit trees or fresh water, which only collects in pits after rain, and that the inhabitants of near-by atolls visit it to collect turtles and birds. Farther on (p. 196) he says that the god of the desert island of Fajo is called Lagé, and (p. 205) he writes:"On the desert island of Fajo, as at Bygar /Bikar in the Marshalls/, fresh water is conjured into the water pits. There is a species of black-bird /probably the frigate-bird, which was sacred on Sorol and Puluwat/ which is under divine protection on this island, and not permitted to be eaten." Chamisso had this information from his friend and informant, Kadu, a native of Woleai.

What then was the real Gaferut? It was either an imaginary magic island, or perhaps a former islet of a reef now devoid of dry land (cf. legend of Ngaruangl in Gressitt 1953, p.2). According to Krämer (1937, foot-note p. 346) Gaferudj is a name for Sëpen, a former atoll near Yap; Müller (1917, p. 304) mentions that Sepin is a sunken magic island, culturally linked to Rumung (northernmost island of Yap). All this might explain why Senfft (1906, p. 284) was told that Gaferut was a devil's island and never visited by the Caroline people, who were afraid of it. The report then would apply to the real Gaferut, rather than to the island we now know under that name, and which Senfft visited (see below).

The confusion of names was recently clarified by Smith (1951, p.28) who calls our Gaferut Fayaew (in his own system of phonetic spelling), and adds (p. 29): "'Gaferut' in turn is a bastardization of a Yapese name, even though Yap has only very remote concerns for that island."

Fayaew belongs to the Faraulep people. When the name Gaferut was first applied (or misapplied) to the coral speck in 9°14'N, 145°23'E has not been ascertained. The island is also called Grimes (Gurimesu-to in Japanese) from Captain Grimes of the ship Jean (Findlay 1870, p. 766), who discovered an island in lat. 9°16'N., long. 145°43'E. He described it as high and well-wooded, of 6 miles in circumference, so there is possibly some confusion with some other island, perhaps Fais. Findlay adds:" It has since been announced as High Island, at lat. 9°11'N., long. 145°45'E. ..." These names are generally considered as synonyms of Gaferut.

One of the few references to Gaferut in the literature is an account of a visit by the German District Administrator of Yap, A. Senfft, in Dec. 1905. He described it (1906) as a flat sand bank, only locally reaching a height of 2 meters. The only vegetation noted was "a species of mangrove." Countless seabirds were nesting in the trees or on the flat ground. Coconut crabs were also observed, and tracks of large sea-turtles. Senfft also noted that a violent storm must have recently hit Gaferut, as most trees had broken branches and some very large ones were completely uprooted. Later, a German expedition exploring for phosphate deposits is said to have discovered phosphate on Gaferut (Aso 1946, p. 117). According to German sources (Sapper 1910) this expedition took place in 1907, not in 1903 as reported in the translation of Aso. As a result of their discoveries, the Germans started exploiting phosphate on Angaur, Peliliu and later Fais, but never on Gaferut. However, the Japanese did mine phosphate there, in spite of great transportation difficulties, starting about 1937.

In addition to the phosphate workers, other Japanese visited Gaferut, among them Yata Haneda, a mycologist interested in luminous fungi, who mentions Gaferut and its phosphate in an account of his 1937 travels in Micronesia (1939). The distinguished geologist Risaburō Tayama apparently also visited Gaferut, and he included a description of it, maps, sections and a photograph in his volumes on coral reefs of Micronesia (1952). He wrote (p. 262): "The table reef of Gaferut is a crude half circle with the convex side facing east. The length of the arc is 1.1 km. Gaferut is the only island on the reef. The shape of the island corresponds roughly to that of the reef. The northern half of the island is chiefly sandy and the southern half primarily gravelly. Recent limestone (Fig. 104) emergent at low tide, is best exposed toward the western end where it strikes northwest and dips 5 to 10 degrees to the southwest. Four recent limestone ridges may be discriminated near the southern coast. The inner ridges are of foraminiferal sandstone and the outer of coral conglomerate; they strike East-West and dip 5 degrees. The central part of the island is flat-topped and rises 5 meters above the reef-flat. The upper surface is level and built of coral limestone (Fig. 105). This limestone is altering to phosphate ore; it conformably overlies a brown clay; and the brown clay, in turn, conformably overlies a foraminiferal sandstone, and the sandstone, the coral gravel and foraminiferal sand bed.

"The reef-flat is extremely wide on the northwest side. The inner zone of the reef-flat is not exposed at low tide, and is dotted with shallow pools about 0.5 meters deep. Seaweeds are growing over the reef floor, and mushroom rocks, 2.5 to 3 meters high, are standing here and there."

Tayama's fig. 103 (p. 116) is a small-scale sketch map with bathymetric contours, and giving 2.7 m as the height of a rock on the NW reef. Fig. 104 (also 146) is a profile of the east coast, from the reef front to the bedded phosphatic rock of the interior, showing a mushroom rock, beach-rock ("recent limestone"), beach sand and gravel between the reef and the phosphate platform. The height of the latter is shown as 5 m above low tide. Fig. 105 is a "Columnar section of beds exposed in pit on Gaferut Island, Gaferut Table Reef," including:

"a. Surface soil-Blackish brown (20 cm)
b. Coral limestone-Phosphatic and include abundant Tridacna gigas (35 cm)
c. Brown clay (25 cm)
d. Foraminifera limestone-Somewhat phosphatic (65 cm)" lying on
"e. Foraminifera and coral sand."

An analysis of the "phosphatic reddish brown clay intercalated in the cay sandstone" is given on p. 265:

SiO_2	CaO	Fe_2O_3	Al_2O_3	P_2O_5
3.28	48.97	3.17	2.50	19.35%

Elsewhere (1942) Tayama had remarked on the amazingly high percentages of silica, iron and aluminum oxides.

In appendix I of the 1952 work is a photo (fig. 48, p. 95) of Gaferut Island. Concerning this F. R. Fosberg says (personal communication): "The presence of bedded phosphate rock on Gaferut suggests that a vegetation of Pisonia grandis may have existed on the island, and the presence of humus on the surface indicates that his must have been in the very recent past. The complete absence of Pisonia now, as indicated by Niering is indeed remarkable. Tayama's photo suggests that Pisonia may possibly have persisted until at least the date of the photo, as the much taller forest on the right side of the picture has the aspect of Pisonia, though the reproduction is so poor that this can be regarded only as an impression rather than a certainty."

There are almost no descriptions of Gaferut in the literature, other than the brief German and Japanese texts. The Sailing Directions (U. S. Hydrographic Office 1938) described it briefly as follows: "low, thickly covered with trees, and encircled by a reef. There are no coconut palms and no inhabitants, but natives from Faraulep Islands visit it to catch birds, which are numerous on it." In a later edition (1952), the information was amended to read: "Gaferut is low and covered with trees. Some of the coconut palms attain a height of 65 feet. There were no permanent inhabitants in 1935, but since that time phosphate mining has been reported. Numerous birds exist on the island, but no food or fresh water.

"The mean high-water interval at the island is 7h. 30m. Mean high-water spring tides rise $2\frac{1}{2}$ feet."

Climate

The climate of Gaferut is a humid tropical one, with little seasonal change. There are no records from the island itself, but in this area of the ocean, temperatures vary little around the year, the mean average air temperature being about 82°F, with daily variations probably not exceeding 15°, and usually less. Atmospheric humidity is always high. It rains throughout the year, with probably higher rainfall in the summer. The total amount of rain must be in the neighborhood of 100 inches (less than Truk to the south and more than Guam to the north). At Lamotrek, somewhat to the south, the rainfall was 104 inches per year, based on 4 years of record.

The wind regime is probably the climatic component most affected by seasonality. The north-east trade winds are rather steady in the winter and spring, and northeast, north and east winds prevail. From June or July to October, the winds are more variable, with often a strong component from southwest, west or south.

Every year some tropical storms or typhoons originate in an area between Gaferut and Truk, and many of them, travelling northwestward toward Guam, must pass near Gaferut. A direct hit is probably not too frequent, but very strong winds and high waves must occur rather often. That Senfft observed the results of the passage of such a storm in 1905 is quite likely. Even Ophelia I, which was so damaging in Jaluit, passed not far from Gaferut toward the end of its destructive career, and so must have Ophelia II (Nov. 30, 1960) which devastated Ulithi. Such storms can occur any month in the year in this part of the Pacific although they are more frequent in the summer and fall.

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A check list of marine algae from Ifaluk Atoll, Caroline Islands

by Isabella A. Abbott[1/]

The marine algae of Ifaluk Atoll and of the Caroline Islands in general appear to be similar to those from the Marshall Islands, as described by Taylor (1950) and Dawson (1956, 1957). The Carolines are for the most part low atolls and their algal floras might be expected to be similar. Some of the volcanic islands in the Caroline group should, on the other hand, furnish a more diverse flora.

The present check-list contains algae collected over a four-month period and represents the most intensive collection of algae from the Caroline Islands. It probably includes 80-90% of the algae of a low atoll near the Equator.

There are a total of 54 new records (31 green algae, 1 brown, 22 red) among 85 species reported here for the Caroline Islands. Schmidt (1928) in summarizing the work of earlier investigators, reported a total of 77 species. To this number, about 20 more species have been reported by various Japanese workers in scattered publications.

I wish to thank Dr. Harold J. Coolidge for making possible a grant of funds from Contract N7onr29116 between the Office of Naval Research and the National Academy of Sciences. I am greatly indebted to my husband, Donald P. Abbott, for making these collections for me. The Ifaluk Survey, sponsored by the Pacific Science Board, took place in 1953 and is described by Marston Bates and D. P. Abbott in the volume Coral Island, Portrait of an Atoll, Scribner's, 1958.

In the list that follows, algae which were collected at more than 10 stations are listed as very common; those collected at 5-10 stations as common; and those at fewer stations as rare. The specimens have been deposited in the University of Michigan (UM), University of California at Berkeley (UC), Bishop Museum (BM), U.S. National Museum (US), and the Chicago Natural History Museum (CM). Some residual collections are at the Hopkins Marine Station of Stanford University (HMS). An asterisk denotes a new record for the Caroline Islands.

Chlorophyceae

*_Enteromorpha lingulata_ J. Ag. Rare. HMS

*_Enteromorpha torta_ (Mertens) Reinbold. Rare. UM, UC, BM, US, CM, HMS.

*_Enteromorpha_ sp. Common. UM, UC, US, CM.

*_Ulvella lens_ Crouan. (On _Microdictyon okamurai_). Rare. HMS.

*_Chaetomorpha antennina_ (Bory) Kützing. Rare. UM.

1/ Research Associate, Hopkins Marine Station of Stanford University, Pacific Grove, Calif.

*Rhizoclonium samoense Setchell, prox. Rare. HMS.

Cladophora sp. Very common. UM, UC, HMS.

*Cladophora fuliginosa Kütz. Common. UM, UC, BM, HMS.

Valonia aegagropila C. Ag. Very common. UM, UC, BM, US, HMS.

*Valonia ventricosa J. Ag. Rare. UM, UC, HMS.

Valonia utricularis C. Ag. Rare. UM, UC, BM, HMS.

Dictyosphaeria cavernosa (Forssk.) Børg. Very common. UM, UC, BM, US, HMS, CM.

*Dictyosphaeria versluysii Weber-van Bosse. Very common. UM, UC, BM, US, HMS.

*Boodlea composita Brand. Very common. UM, UC, BM, US, CM, HMS.

Anadyomene wrightii Gray. Rare. UM, UC, HMS.

Microdictyon okamurai Setchell. (The commonest marine alga). UM, UC, BM, US, CM, HMS.

Caulerpa antoensis Yamada. Very common. UM, UC, BM, US, CM, HMS.

*Caulerpa ambigua Okamura. Rare. UM.

*Caulerpa bikinensis Taylor. Rare. UM.

Caulerpa serrulata (Forssk.) J. Ag. (and varieties). Very common. UM, UC, BM, US, CM.

Caulerpa urvilliana Montagne (and forms). Very common. UM, UC, BM, US, HMS, CM.

*Bryopsis sp. Rare. HMS.

Udotea argentea Zanardini. Common. UM, UC, BM, US, HMS, CM.

*Udotea indica A. and E. S. Gepp. Rare. UM, UC, HMS.

*Udotea orientalis A. and E. S. Gepp. Rare, UM, UC, BM, HMS.

*Avrainvillea obscura J. Ag. Rare. UM, UC, BM, HMS.

Avrainvillea sp. UM, UC, CM.

*Rhipilia diaphana Taylor. Rare. UM.

*Rhipilia geppii Taylor. Common. UM, UC, BM, US, HMS, CM.

*Rhipilia orientalis A. and E. S. Gepp. Common. UM, UC, BM, US, HMS.

*Halimeda fragilis Taylor. Rare. HMS.

*Halimeda gracilis Harvey (and form). Very common. UM, UC, BM, US, HMS, CM.

*Halimeda lacunalis Taylor. Rare. UM, UC.

Halimeda micronesica Yamada. Very common. UM, UC, BM, US, HMS, CM.

Halimeda opuntia (L.) Lamx. (and forms). Very common. UM, UC, BM, US, HMS, CM. Note: The formae elongata, hederacea, triloba and renschii are distributed between UM, UC, and BM.

*Halimeda stuposa Taylor. Very common. UM, UC, BM, US, HMS, CM.

*Halimeda taenicola Taylor. Common. UM, UC, BM, US, HMS.

Halimeda tridens (Ellis et Sol.) Lamx. Rare. UM, UC.

Halimeda sp. UM. (7 specimens).

*Halicoryne wrightii Harvey. Rare. UC.

*Neomeris annulata Dickie. Rare. HMS.

*Neomeris vanbosseae Howe. Rare. UM, UC.

*Acetabularia parvula Solms-Laubach. Common. UM, UC, BM, US, HMS.

*Vaucheria sp. Rare. HMS.

*Dichotomosiphon sp. Rare. UM, HMS.

*Pseudodichotomosiphon constricta Yamada. Rare. UM, UC, BM, HMS.

Phaeophyceae

*Ectocarpus mitchellae Harvey. Rare. UM, UC.

Sphacelaria sp. HMS.

Pocockiella variegata (Lamx.) Papenf. Very common. UM, UC, BM, US, HMS, CM.

Rhodophyceae

Asterocytis ornata (C. Ag.) Hamel. Rare. UM, UC, US.

*Goniotrichum elegans (Chauvin) Zanard. Rare. HMS.

Erythrotrichia carnea (Dillwyn) J. Ag. Rare. UC.

*Liagora ceranoides Lamx. Rare. UM, UC, BM, US, HMS.

*Liagora kahukuana Abbott. Rare. UM, UC, BM, US, HMS.

*Liagora sp. (3 collections). HMS.

*Galaxaura filamentosa Chou. Rare. UM, UC, HMS.

Galaxaura fastigiata Decaisne. Rare. UM, HMS.

*Goniolithon frutescens (Foslie) Foslie. Rare. UM, UC, HMS.

*Porolithon onkodes (Heydrich) Foslie. Very common. UM, UC, BM, US, HMS, CM.

*Porolithon gardineri (Foslie) Foslie. Very common. UM, UC, BM, US, HMS.

*Porolithon aequinoctiale (Foslie) Foslie. Common. UM, UC, BM, US, HMS.

*Porolithon sp. (4 specimens). UM, UC, BM.

*Lithothamnion sp. Common. UM, UC, BM, HMS.

*Fosliella farinosa (Lamx.) Howe. Very common on other algae.

Jania sp. Very common. UM, UC, BM, US, HMS.

Hypnea nidulans Setchell. Rare. UM, UC, BM, US, HMS, CM.

*Hypnea spinella (C. Ag.) Kützing. Common. UM, UC, BM, US, CM.

*Wurdemannia miniata (Drap.) Feldmann et Hamel. Rare. HMS.

*Rhodymenia sp. Rare. HMS.

*Ceramium sp. Common. UM, UC.

Centroceras clavulatum (C. Ag.) Montagne. Rare. UC.

Centroceras minutum Yamada. Common. UM, UC.

*_Antithamnion_ sp. Rare. HMS.

*_Griffithsia tenuis_ C. Ag. Rare. HMS.

*_Griffithsia rhizophora_ (Grun.) Weber-van Bosse. Rare. HMS.

Haloplegma duperreyi Montagne. Common. UM, UC, BM, US, HMS, CM.

Heterosiphonia wurdemannii (Bail.) Falkenb. Rare. HMS.

Dasya adhaerens Yamada. Rare. UM, UC.

Hypoglossum minimum Yamada. Rare. UM.

*_Polysiphonia subtilissima_ Montagne. Very common. UM, UC, US, HMS, CM.

*_Herposiphonia tenella_ (C. Ag.) Naegeli. Very common. UM, UC, BM, US, HMS.

Leveilleia jungermannioides (Mart. et Her.) Harvey. Rare: Occurring on species of _Halimeda_. UM, UC, BM.

*_Laurencia mariannensis_ Yamada. Very common. UM, UC, BM, HMS, US.

Laurencia perforata (Bory) Montagne, prox. Common. UM.

Laurencia sp. (two specimens). UM.

Chondria sp. (1 specimen). HMS.

Angiospermae

Halophila ovalis R. Br. Common. UM, UC, BM, US, HMS.

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ATOLL RESEARCH BULLETIN

No. 78

Narrative report of botanical field work on Kure Island, 3 October 1959 to 9 October 1959

by

Horace F. Clay

Issued by

THE PACIFIC SCIENCE BOARD

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Washington, D. C.

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Narrative Report of Botanical Field Work on Kure Island

3 October 1959 to 9 October 1959

by Horace F. Clay
University of Hawaii

Kure (often referred to as Ocean Island) is the most western island in the Hawaiian Archipelago. It is located about 1250 miles west of Honolulu. The atoll is described, with map and bibliography, in E. H. Bryan, Jr., American Polynesia and the Hawaiian Chain, Honolulu, 1942.

In order to make Kure Island more habitable to the blackfooted and Laysan Albatrosses, the Naval Construction Forces of the Pacific in October 1959 planned to bulldoze a series of runways 100 yards long and 50 feet wide on Kure Island. This is a report of the botanical field work carried on in conjunction with that Navy project.

The State of Hawaii, through its Land Commissioner, Mr. Eric Reppun, gave the Navy permission (Revocable Permit No. 2580) to make the alterations to Kure Island. The State of Hawaii, however, stipulated that two types of plants be preserved on Kure Island, Lepturus repens and Solanum nelsoni var. intermedium (now Solanum nelsoni). The writer, familiar with atoll floras, was invited to join the group going to Kure, so that identification could be made of the plants growing on that island.

A previous collection of plants had been made by the Tanager Expedition in April 1923. In that year, thirteen species of vascular plants were collected on Kure. Eleven of these thirteen species are still growing there; Cenchrus agrimonioides var. laysanensis and Achyranthes splendens var. reflexa, represented by a very few specimens in 1923, have disappeared*. However, six new species have found their way to Kure, so the flora there now comprises seventeen kinds of plants.

Green Island, the largest of the three islets at Kure Atoll, is the only one on which there is any higher plant life. The other two islets are tiny sand-spits. Green Island is approximately three-fourths of a mile long, about one-half mile wide, and has an elevation of some 20 feet. There is a dense growth of Scaevola sericea which encircles and covers most of Green Island. Scattered here and there among these Scaevola plants are patches of Boerhavia diffusa which sometimes appear as a loose ground cover under the Scaevola and frequently can be seen as scrambling vine-like plants. Sand dunes rise sharply from the beach on the lagoon side, and the Scaevola sericea is less dense here. In the open areas along the dunes, one can observe scattered clumps of the bunch grasses, Eragrostis variabilis and Eragrostis whitneyi var. caumii. On the inner slopes of the dunes near the radar reflector tower, several dozen clumps of Lepturus repens can be found. With the exception of three clumps of this grass on the dunes at the eastern tip of Green Island, Lepturus repens was only observed near the radar reflector tower.

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* These two species, while not in evidence in 1959, were found again in 1961 by Ch. Lamoureux, cf. Bulletin 79.

Since Cynodon dactylon, Casuarina equisetifolia (4 of the 6 existing specimens on Green Island), Pluchea odorata and Verbesina encelioides seem to be localized on the dunes near the radar reflector tower which was constructed in 1955, it is surmised that seeds of these plants were brought on equipment from the Island of Midway.

One very young specimen of Messerschmidia argentea, the only one on Green Island, was found growing on the windward shore.

An open plain of about 25 acres comprises the central-eastern portion of the islet. On this plain were found Lepidium owaihiense, Tribulus cistoides, Ipomoea indica, Solanum nelsoni, Solanum nigrum, Sicyos hispidus, and Lipochaeta integrifolia. These plants were only found on the plain and not in any other areas of Green Island.

Two different saprophytic fungi were found, both associated with decaying stems of Scaevola sericea. These fungi have not been identified.

As a matter of interest, during the seven days that the author spent on Kure, seeds were collected in the beach drift. The following were found during this period: Cocos nucifera - 7 dead nuts, Aleurites moluccana - 9 dead nuts, and Mucuna gigantea - 1 seed.

The following is a total list of the plants collected on this expedition. Those marked with an asterisk are new since the Tanager Expedition, April 1923.

*2 Fungi

Gramineae:

*Cynodon dactylon (L.) Pers.

Eragrostis variabilis (Gaud.) Steud.

Eragrostis whitneyi Fosb. var. caumii Fosb. /E. falcata/

Lepturus repens (Forst.) R. Br.

Casuarinaceae:

*Casuarina equisetifolia L.

Nyctaginaceae:

Boerhavia diffusa L.

Cruciferae:

Lepidium owaihiense Cham. & Schlecht.

Zygophyllaceae:

Tribulus cistoides L.

Convolvulaceae:

Ipomoea indica (Burm.) Merr.

Boraginaceae:

*Messerschmidia argentea (L.) Johnston (photo only)

Solanaceae:

Solanum nelsoni Dunal

*Solanum nigrum L.

Cucurbitaceae:

Sicyos hispidus Hbd.

Goodeniaceae:

Scaevola sericea Vahl

Compositae:

Lipochaeta integrifolia (Nutt.) Gray

*Pluchea odorata (L.) Cass.

*Verbesina encelioides Gray

On the beach were found:

Cocos nucifera L., 7 dead nuts

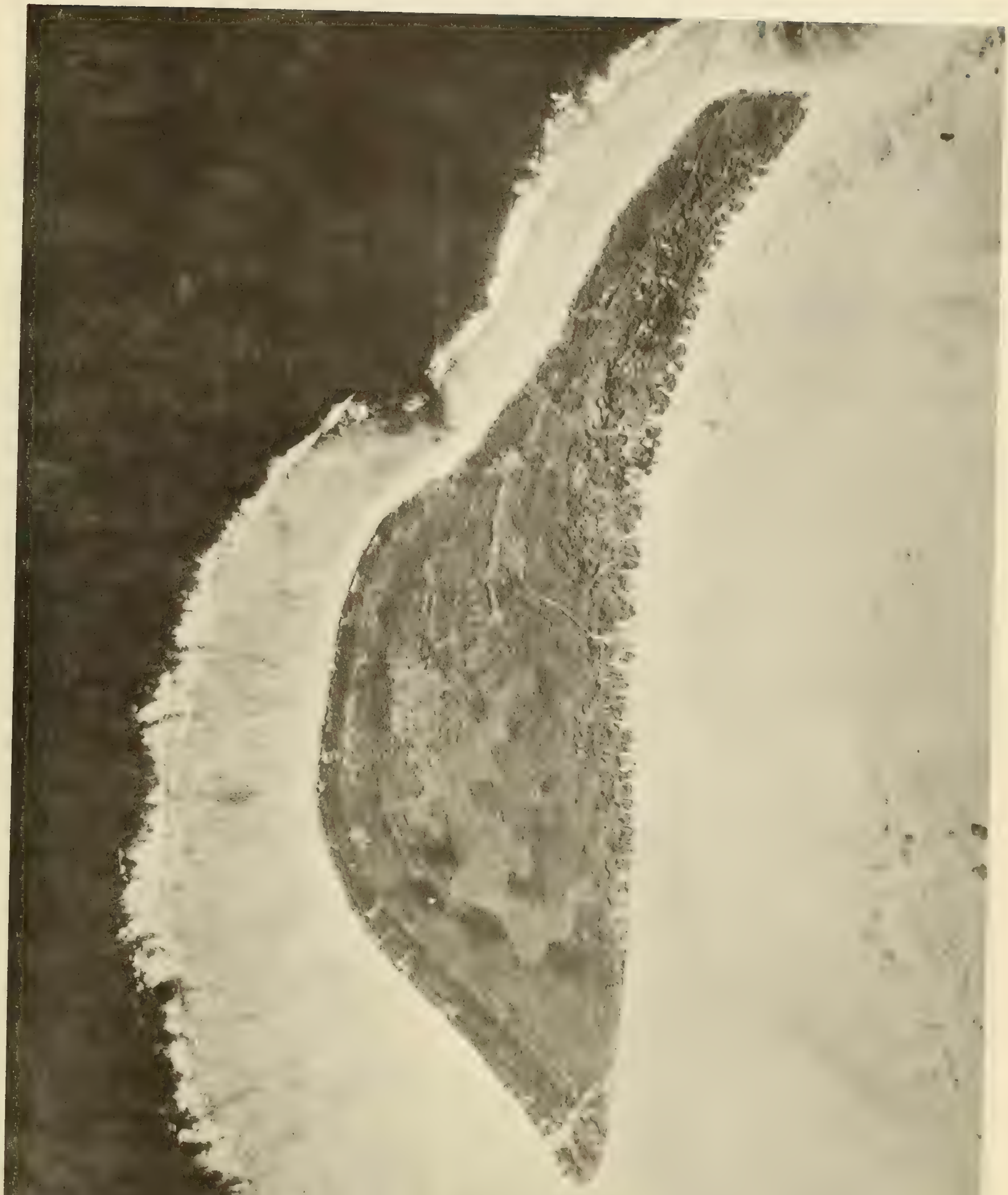
Aleurites moluccana Willd., 9 nuts

*Mucuna gigantea (Willd.) DC., 1 seed

Herbarium specimens and photographs in the field of the plants collected on this trip are located in the Herbarium of the Bishop Museum, Honolulu, Hawaii, and in the U.S. National Herbarium, Washington, D. C.

Photos: Green Island, Kure Atoll, from air, October 3 and November 3, 1959, before and after "habitat improvement".

Photos courtesy of U. S. Navy



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No. 79

Botanical observations on Leeward Hawaiian Atolls

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Botanical Observations on Leeward Hawaiian Atolls

by

Charles H. Lamoureux[1]

I. Notes on the plants of Kure Atoll

Through the courtesy of the United States Coast Guard and Dr. H. J. Coolidge, the writer was able to visit Kure Atoll from September 12 to 14, 1961. The observations made at this time will serve as a supplement to Dr. Clay's (see ARB no. 78) report. I wish to thank Drs. George Butler, M. D. F. Udvardy, Robert Usinger, and Mr. David Woodside for calling my attention to certain plants.

Since Dr. H. F. Clay visited Kure in October, 1959, a U. S. Coast Guard Loran Station has been constructed there on Green Island. Among the facilities now present on the island are a landing strip paved with crushed coral over asphalt, a series of buildings and a 625 foot radio tower. As a result of the disturbances caused by activities involved in the construction of these facilities and the intentional and unintentional introduction of plants concomitant with such activities, there have been significant changes in the flora and vegetation of the island within the past two years.

All 13 species of vascular plants collected in 1923 by the Tanager Expedition (Christopherson and Caum, 1931) were still growing on Kure during the present visit in 1961. Of the six species first reported by Clay (ARB 78), all but Pluchea odorata were collected. In addition one presumed native species, Phyllostegia variabilis, and 22 species of newly introduced weeds and cultivated plants are here reported from Kure for the first time. Thus the flora now contains 41 species of vascular plants.

The Commanding officer of the Loran Station informed us that approximately 1500 plants for use in landscaping were flown in from Honolulu in March, 1961. Those which have survived are planted in the clearing around the buildings and the tennis court. In addition, Cynodon dactylon has been planted as a lawn grass and appears to be thriving. Another 200 pounds of seed of this species is being sown to create more lawn area. The introduction of more shade tree species is being considered. Some of the weed species were obviously introduced with the plants from Honolulu since they occur either in the cans with these plants or a short distance from the cans and not elsewhere on the island. Other weedy species are at present restricted to road margins or other disturbed areas and may have come in with some of the heavy construction equipment. One plant of Spergularia marina found growing in the middle of the airstrip may well have developed from a seed transported to Kure in the landing gear of some aircraft. This Spergularia is abundant on the margins of the airstrip at French Frigate Shoal, although it has not been reported from Midway.

1/ Department of Botany, University of Hawaii.

During the stay on Kure the larger of the two sand islands was visited. This island is about 400 meters long, 10 to 20 meters wide and reaches a maximum elevation of about one meter. The vegetation consisted of less than a dozen scattered plants of Boerhavia diffusa and one tiny clump of Eragrostis whitneyi var. caumii. Observation of the smaller sand island (50 m. by 10 m.) from a distance of approximately 50 meters revealed no sign of vascular plants. All other species are restricted to Green Island.

Specimens cited below were collected and identified by the author and have been deposited in the herbarium of the Bernice P. Bishop Museum, Honolulu 17, Hawaii. The initials "CHL" identify the author's collection numbers. No specimens of cultivated plants were made. New records are indicated by *.

PANDANACEAE

*Pandanus sp. Variegated variety planted near the living quarters.

GRAMINEAE

Cenchrus agrimonioides var. laysanensis F. Br. Half a dozen clumps in one small area of the central plain, intermixed with Boerhavia and Scaevola. CHL 1912.

*Cenchrus echinatus L. Two plants observed, one near the living quarters, the other near the east end of the landing strip. Both had set large quantities of seed so this plant will probably spread. CHL 1908.

*Chloris inflata Link. Disturbed areas near quarters and on roadsides. CHL 1907.

*Chloris virgata Swartz. Disturbed areas near quarters. CHL 1887.

Cynodon dactylon (L.) Pers. On dunes and beach near radar reflector tower, and used around quarters as lawn grass. CHL 1866, 1884, 1885.

*Digitaria sanguinalis (L.) Scop. Disturbed areas near quarters. CHL 1864.

*Eleusine indica (L.) Gaertn. Disturbed areas near quarters. CHL 1888.

*Eragrostis amabilis (L.) W. & A. Disturbed areas near quarters. CHL 1862.

Eragrostis variabilis (Gaud.) Steud. Fairly abundant in open areas of eastern-central plain. CHL 1868, 1869.

Eragrostis whitneyi var. caumii Fosb. Common in open sandy areas on lagoon side. One clump on the larger sand island. CHL 1861, 1867, 1870, 1893.

Lepturus repens var. *subulatus* Fosb. Several clumps near radar reflector tower and near east end of plain. CHL 1873.

**Setaria verticillata* (L.) Beauv. One plant near the west end of the landing strip. CHL 1906.

CYPERACEAE

**Cyperus rotundus* L. A few plants in disturbed areas near quarters. CHL 1905.

PALMAE

**Cocos nucifera* L. Seedlings planted near quarters.

CASUARINACEAE

Casuarina equisetifolia L. In addition to the larger trees reported by Clay (ARB 78), several young plants are being grown around the quarters. CHL 1886.

AMARANTHACEAE

Achyranthes splendens var. *reflexa* Hbd. Here and there on the central plain. CHL 1875, 1894.

NYCTAGINACEAE

Boerhavia diffusa L. Abundant all over Green Island under and around *Scaevola* bushes and on the central plain. *Boerhavia* is growing rapidly in recently cleared areas and has covered the albatross runways which were cleared in October 1959. It is growing through the black-top at the east end of the landing strip. About a dozen plants are growing on the larger sand island. CHL 1860, 1876, 1877, 1881, 1882.

CARYOPHYLLACEAE

**Spergularia marina* (L.) Griseb. One plant growing in the center of the landing strip, a few others noted along the road leading to the radio tower. CHL 1910.

CRUCIFERAE

Lepidium o-waihiense C. & S. Abundant on the central plain and invading areas recently cleared for installation of radio tower guy wires. CHL 1872.

ZYGOPHYLLACEAE

Tribulus cistoides L. Here and there in the central plain and on roadsides. CHL 1874.

EUPHORBIACEAE

*_Codiaeum_ sp. Cultivated near quarters.

*_Euphorbia glomerifera_ (Millsp.) Wheeler. Weed in cans with cultivated plants near quarters and spreading into open areas nearby. CHL 1863, 1904.

MALVACEAE

*_Hibiscus_ sp. Cultivated near quarters.

*_Thespesia populnea_ (L.) Sol. Cultivated near quarters.

COMBRETACEAE

*_Terminalia catappa_ L. Cultivated near quarters.

APOCYNACEAE

*_Nerium oleander_ L. Cultivated near quarters.

CONVOLVULACEAE

Ipomoea indica (Burm. f.) Merr. Common on central plain. CHL 1880.

BORAGINACEAE

Messerschmidia argentea (L.f.) Johnston. Several trees near eastern tip of island, one on south-central part. CHL 1895.

LABIATAE

*_Phyllostegia variabilis_ Bitter. Two sterile plants were found on the central plain growing in a patch of _Boerhavia diffusa_ and _Solanum nelsoni_ about 100 meters from the tennis courts. The vegetative characters match those of _Phyllostegia variabilis_, a species previously recorded only from Laysan and Midway. Certain identification, however, awaits the collection of fertile material. CHL 1926.

SOLANACEAE

Solanum nelsoni Dunal. Common around edges of and occasionally in Scaevola thickets on central plain. CHL 1878, 1879, 1898.

Solanum nigrum L. Common on central plain, especially in disturbed areas. CHL 1897.

CUCURBITACEAE

Sicyos hispidus Hbd. Common on central plain. CHL 1899 - 1903.

GOODENIACEAE

Scaevola sericea Vahl. Abundant all over island forming dense thickets from one to three meters high. CHL 1871, 1890, 1891.

COMPOSITAE

*Conyza bonariensis (L.) Cronq. One clump noted near quarters. CHL 1909.

*Emilia javanica (Burm.) Rob. Weed in cans with cultivated plants near quarters and spreading into open areas nearby. CHL 1864.

*Gnaphalium sandwicensium Gaud. Abundant in recently cleared areas around quarters. CHL 1889, 1892.

*Helianthus annuw L. Cultivated near quarters.

Lipochaeta integrifolia (Nutt.) Gray. Common on central plain, moving into disturbed areas. CHL 1911.

*Sonchus oleraceus L. Disturbed areas near quarters. CHL 1883.

Verbesina encelioides (Cav.) B. & H. Several plants near radar reflector tower and spreading onto nearby lagoon beach, with seedlings also present in disturbed areas near quarters. CHL 1896.

The disturbed areas, which are the places where the greatest vegetational changes are to be expected, are of four general types:

a. Margins of roads and landing strip. Boerhavia diffusa has covered most of the margin of the landing strip, with Tribulus cistoides and some of the weedy grasses occurring as scattered individuals. Along the roadsides Boerhavia is somewhat less abundant with a larger proportion of weeds. In one place where a road is cut through a sand dune, Eragrostis whitneyi var. caumii is growing well.

b. Albatross runways. These were cleared in October, 1959. The parts which were not obliterated by the landing strip are now partially to completely covered with *Boerhavia*.

c. Clearings around living quarters. *Gnaphalium sandwicensium* is extremely abundant in areas where *Cynodon dactylon* has not been planted. *Euphorbia glomerifera*, *Emilia javanica*, *Conyza bonariensis*, and *Eragrostis amabilis* were found only here at the time the study was made.

d. Clearing around radio tower. A series of cleared strips a few meters in width radiate out from the base of the tower to the guy-wire anchors. These strips cut through most of the eastern part of the central plain. *Boerhavia diffusa*, *Lepidium o-waihiense*, *Lipochaeta integrifolia*, and *Solanum nigrum* are moving into these areas.

It is too early to predict the total impact of the recently introduced plants on the indigenous species. However, if no further major construction occurs, most of the indigenous plant species are present in numbers large enough that they do not appear to be in immediate danger. There are two exceptions to this statement, *Cenchrus agrimonioides* var. *laysanensis* and *Phyllostegia variabilis* (if our plant proves to be this species). *Cenchrus* is no longer to be found on Laysan and has not been collected on Midway since 1902. The few plants remaining on Kure should receive some measure of protection. *Phyllostegia* is also extinct on Laysan and has not been collected on Midway since 1923. The Kure plant should be watched to verify the determination and should also be protected.

Photo: Green Island, Kure Atoll, view from southwest 1961, showing airstrip and installations.

Photo courtesy of U. S. Coast Guard.

II. Vascular plants of Tern Island, French Frigate Shoal

Through the courtesy of the United States Coast Guard and Dr. Harold F. Coolidge, the author was able to visit Tern Island on September 2, 1961. Since only half an hour ashore was available, during which time a circuit of the island was made, the observations reported here should be considered as "preliminary". I wish to express my appreciation to H. Ivan Rainwater who supplied me with a list of his collections from French Frigate Shoal, and to Dr. V. J. Krajina and Miss Marie Neal who assisted in the identification of the material designated here as Atriplex muelleri.

French Frigate Shoal, about 480 miles northwest of Honolulu, is a crescent-shaped atoll on which are a number of sand islets. A few miles to the southwest are two rock islets, remnants of the original volcanic island. Tern Island, one of the sand islets (23° 54' N. Lat., 166° 19' W. Long.), is now the site of an airstrip and a United States Coast Guard loran station.

The botanical history of Tern Island is brief. The Tanager Expedition in 1923 (Christophersen and Caum, 1931) found five species of vascular plants growing there: Lepturus repens, Chenopodium sandwicheum, (now C. oahuense), Boerhavia diffusa, Portulaca lutea and Tribulus cistoides. During World War II the airstrip was constructed and some time later the loran station was built. H. Ivan Rainwater made plant collections on Tern and other islands in October, 1953. The second published observations were by Svihla (1957), who visited the island in 1956, and reported that the flora consisted of "various grasses", Ipomoea pes-caprae, Scaevola (probably S. sericea although no species was cited), and cultivated plants of Cocos nucifera and Casuarina sp.

Most of the surface of Tern Island is now occupied by the crushed coral airstrip which is 3100 feet long and drops off sharply into the water at the east and west ends. Along the south edge of the airstrip is an unpaved area 10 to 50 meters wide on which the living quarters are located. There is an extensive sandy beach along the south shore. On the north edge of the airstrip the unpaved area is up to 20 meters wide and there are only a few small sandy beach areas. The island is about two meters high. It is likely that little, if any, of the surface of the island was left untouched when the airstrip was constructed (see note p. 10).

The unpaved area south of the airstrip is rather densely covered with shrubs of Messerschmidia argentea and Pluchea odorata, and an herbaceous cover in which the predominant species are Ipomoea pes-caprae, Boerhavia diffusa, Cenchrus echinatus, Setaria verticillata, Sonchus oleraceus, and Conyza bonariensis. Of less frequent occurrence here are Eleusine indica, Lepturus repens, Portulaca lutea and P. oleracea. One large clump of Scaevola sericea is present southwest of the living quarters. Spergularia marina is abundant on the margins of the airstrip. The unpaved area on the north side of the island is less densely vegetated than that on the south. Pluchea odorata is present, but the shrubs are widely scattered. Very few plants of Messerschmidia argentea are present.

The herbaceous species are the same as those on the south except that Tribulus cistoides and Cynodon dactylon are also present on the north. Atriplex muelleri was found only in a single locality at the west end of the airstrip.

Cultivated plants around the Coast Guard quarters include Cocos nucifera, Casuarina equisetifolia, Ficus sp., Coccoloba uvifera, and Plumeria obtusa.

Of the five species noted by Christophersen and Caum (1931) for Tern Island all but Chenopodium oahuense were collected in 1961. The four species named by Svihla (1957) were still present. Fourteen additional species of weeds and cultivated plants are reported here for the first time. The flora now contains 22 species of vascular plants.

While it is impossible to determine the modes of introduction of the weedy species, it seems likely that the seeds of some of these came to the island in the soil which was reportedly brought there from Honolulu (Svihla, 1957). Honolulu was probably the place from which the cultivated plants were obtained. Other weedy species may have reached Tern Island accidentally via construction equipment, aircraft, or personnel. One cannot completely discount the possibility of "natural" dispersal by wind, birds, or ocean currents. However, most of the weedy species were present in the main Hawaiian Islands for many years before 1923, but the species were not found on French Frigate Shoal then. Thus, the weeds appeared there only after man began to make frequent visits.

The specimens cited below are deposited in the herbarium of the Bernice P. Bishop Museum, Honolulu 17, Hawaii. The initials "CHL" identify the author's collections made on September 2, 1961. The initials "HIR" indicate that the species was collected by H. Ivan Rainwater in October, 1953; "AS" indicates the species was collected by Arthur Svihla in February, 1956. The collections of Rainwater and Svihla were not numbered. New records are indicated by *.

GRAMINEAE

*Cenchrus echinatus L. CHL 1661.

*Cynodon dactylon (L.) Pers. CHL 1673.

*Eleusine indica (L.) Gaertn. CHL 1662, AS.

Lepturus repens (Forst.) R. Br. var repens. CHL 1668, 1674, HIR, AS.

*Setaria verticillata (L.) Beauv. CHL 1669, 1670, HIR, AS.

PALMAE

Cocos nucifera L. (Specimens not collected).

CASUARINACEAE

Casuarina equisetifolia L. CHL 1651.

MORACEAE

*Ficus sp. CHL 1659.

POLYGONACEAE

*Coccoloba uvifera (L.) Jacq. CHL 1660.

CHENOPODIACEAE

*Atriplex muelleri Benth. CHL 1654, HIR.

NYCTAGINACEAE

Boerhavia diffusa L. CHL 1671, 1675, HIR, AS.

PORTULACACEAE

Portulaca lutea Sol. CHL 1667, HIR.

*Portulaca oleracea L. CHL 1666.

CARYOPHYLLACEAE

*Spergularia marina (L.) Griseb. CHL 1663.

ZYGOPHYLLACEAE

Tribulus cistoides L. CHL 1652, HIR, AS.

CONVOLVULACEAE

Ipomoea pes-caprae (L.) Sw. CHL 1658, HIR.

APOCYNACEAE

*Plumeria obtusa L. CHL 1650.

BORAGINACEAE

*Messerschmidia argentea (L.f.) Johnston. CHL 1653, HIR.

GOODENIACEAE

Scaevola sericea Vahl. CHL 1656, HIR.

COMPOSITAE

**Conyza bonariensis* (L.) Cronq. CHL 1655, 1665.

**Pluchea odorata* (L.) Cass. CHL 1657, 1672, HIR, AS.

**Sonchus oleraceus* L. CHL 1664, AS.

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Note -- The statement on p. 7, "It is likely that little, if any, of the surface of the island was left untouched when the airstrip was constructed," has recently been confirmed by Dr. Vernon E. Smith of Kaneohe, Hawaii. Dr. Smith tells me that he spent several days on Tern Island in 1948, at which time he did not observe any higher plants growing on the island.

ATOLL RESEARCH BULLETIN

No. 80

The tropical coral reef as a biotope

by

Sebastian A. Gerlach

Translated by Alan J. Kohn

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The tropical coral reef as a biotope

by Sebastian A. Gerlach
Zoological Institute, University of Kiel, Germany

Translated by Alan J. Kohn
Department of Biological Sciences
Florida State University
Tallahassee, Florida

On few marine habitats is there such a voluminous literature as on tropical coral reefs. However, most studies have been concerned with very well defined problems, primarily with the laws of growth of reefs and with theories which explain the origin of coral reefs and coral islands through the combination of biological and geological factors.

Only recently has there been concern with detailed studies of the living habits of coral polyps, of their nutrition, and of their dependence on different environmental conditions. Similarly, the various ecological zones of which the coral reef is composed have only been clearly defined in recent times and confirmed through faunistic studies. Here may be cited the works on fishes of a Pacific atoll by Harry (1953) and on the mollusks by Morrison (1954), works which confirm the validity of the reef zones distinguished by Tracey, Cloud and Emery (1955).

In contrast, for other groups of animals, the only statements at our disposal are those found scattered in the systematic and faunistic literature, together with the individual observations of various naturalists. No comprehensive summary seems to have been made as yet. Until recently, literally nothing was known about the microfauna of tropical coral reefs; indeed, it was not even known whether a microfauna could find the appropriate conditions essential for life in the environment of the coral reef.

I had the opportunity to study coral reefs in the Red Sea and the Maldive Archipelago (Indian Ocean) during the "Xarifa-Expedition 1957/1958."[1] Moreover the microfauna was the focus of the research; thirty samples from coral biotopes were collected in the Red Sea and 84 samples in the Maldives. The systematic study, by various specialists, of the assembled material has not yet been completed; therefore, a complete faunal list cannot be presented, and the following remarks must be considered as preliminary results, and they will have to be completed and enlarged after the conclusion of the systematic studies.

In the Maldive Archipelago the reefs and coral islands are always assembled in atolls and, like a string of pearls, enclose a lagoon 40-60 m. in depth. Channels cross the reef at many places and link the lagoon with the open sea. In addition, small reefs, which grow up from the lagoon floor without having any connection with the encircling reef, are found in many places.

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[1] At this point I would like to thank Dr. Hans Hass, as whose guest I was able to work for seven months on the ship "Xarifa".

One must, therefore, distinguish between outer reef and lagoon reef. The outer reef is exposed to the breakers of the open ocean. A steep slope reaches up from the depths of the sea to a ledge, five to ten meters below the surface, which extends landwards as a reef terrace. Then the reef rises up to low tide level and there forms a characteristic zone under the influence of the heavy surf. Here calcareous algae of the group of Lithothamnion find especially favorable living conditions, coating the coral that grows there with a crimson red layer and also forming reef limestone themselves. From this Lithothamnion-zone a flat reef platform extends landward, situated just below low tide level and overgrown with small corals of various species, with alcyonarians, zoantharians and algae. Heliopora is also found here at low tide level.

The conditions described above were encountered on the reef of Hitadu Island, Addu Atoll, Maldives. In front of some other atoll islets, such a reef flat is lacking, but there is either a zone of sand stretching between the islet shore and the reef, or a zone of detached coral boulders.

A zone of sand separates the lagoon shore from the lagoon reef. The lagoon reef itself rises in pinnacles just to low tide level and is composed of many different species of corals. Here especially are found the branching, brittle forms.

Thus we can distinguish between different reef zones, which are characterized by different water depths and different influences from wave action. The analysis of the microfauna--as far as carried out--shows, however, only surprisingly insignificant variation between the individual reef zones: Exposed outer reef, protected lagoon reef, and the blocks of coral growing at depths of 10-30 m. exhibit a very closely similar fauna. Among the free-living nematodes a few species can be found which particularly prefer the flat coral biotope lying near low tide level, and it is likely that additional species with more specialized requirements will be found when the systematic study of the other groups is also completed, but the uniform character of the coral fauna is so striking, that individual differenciations can only play a subordinate role.

Such an ecological situation is in contrast with the conditions on sandy and soft sea bottoms, where both the force of the water movement and related with it the particle-size distribution and nature of the sediments, and the depth of water, have a great influence on the microfauna, so that one hardly expects to find any common species among the representatives of the microfaunas of an exposed beach and the sea bottom of a protected bay.

On the contrary, all of the coral zones investigated are inhabited by quite a uniform microfauna, and separation into particular biocoenoses does not appear justified, at least not now, because special character species which could identify the particular zones are lacking.

We shall now attempt to compare the microfauna of the coral heads with the fauna of other marine environments, since the considerable uniformity between coral fauna and "phytalfauna", the fauna which inhabits algae, hydroid colonies, and bryozoan colonies, is striking.

Thirty-six species of free-living marine nematodes were found on coral heads in the Red Sea (Gerlach, 1958). Of these, four species were new to science; most of the remainder had been collected previously by other authors in the Mediterranean Sea, Red Sea or Indian Ocean, and there among algae. The study of the nematode fauna of coral samples from the Maldives is leading to similar results, and Herr Dr. G. Hartmann (of Hamburg; oral communication), who is studying the ostracods of my collection, has come to the same conclusion.

On the lagoon reef of Welingandu Island, Rasdu Atoll, Maldives, I had the opportunity to make a series of 18 samples of the different species of corals occurring there, for their microfauna. This demonstrated again that the free-living marine nematode fauna shows no variation--is entirely the same--whether it inhabits branching corals such as Stylophora, Pocillopora and Psammocora or massive, globular heads such as Porites, Favites, and Leptoria. Further, it also showed that the same nematode fauna occurs on corals which have died off and on which a crust of calcareous algae and other forms has developed. And finally, samples from Alcyonaria and the calcareous green alga Halimeda are not different from samples collected from living coral.

Only quantitative differences can be established, and these are closely related to the capacity of the coral polyps to secrete mucus. Upon irritation, the epidermis of the coral polyp secretes mucus, in which foreign objects fallen on the surface and small organisms become entangled; they are, together with the mucus, carried by ciliary movement to the edge of the coral head, and they fall to the bottom. There are corals, mainly those of the genus Acropora, which secrete mucus in great quantities. The sparsest microfauna is found on the heads of this species, and I have studied a series of Acropora samples usually without finding any associated fauna. In contrast, the richly populated corals such as Seriatopora, Pocillopora and Stylophora produce a distinctly smaller amount of mucus. Beyond this, whether this may also depend on the possibly different efficiency of the nematocysts of the corals is not yet known.

Therefore, I would characterize the nematode fauna, and probably the entire microfauna of coral heads as "phytalfauna" and include the coral reef among the "phytal" biocoenoses. The population density is great on dead corals which are overgrown with algae; in contrast, on living corals it is generally smaller. The coral reef thus represents an environment which apparently provides less favorable living conditions for the microfauna than does an abundant growth of red algae.

Of course, as stated above, the systematic work on the collected material is not yet completed, and it is possible that in the other animal groups of the microfauna, representatives will be found which are typical of the coral reef and do not occur in algal zones. An as yet unidentified aberrant copepod with a wormlike body, which apparently lives only on coral, mainly Pocillopora, certainly belongs here. These animals could be observed as they crawled about on the surface of the coral and slashed at the tissues of the polyps with the sharp claws of the first pair of legs. Here the point to be considered is that this is a form which has become particularly adapted to a mode of life

parasitic on coral. /Dr. Gerlach has kindly informed me in a letter that since publication of the original report, this form has been described by A. G. Humes (Kieler Meeresforsch., 16: 229-235, 1960) as a member of the new genus Xarifa of the new family Xarifiidae.--AJK/

No relations could be found with the fauna of the interstices of the sand. To be sure we found Ingolfiella litoralis Hansen, a slender isopod 2 mm in length, of which only a single specimen was previously known from coral from the Gulf of Siam. Ingolfiella ruffoi Siewing lives in coastal ground water, other species live in fresh ground water in the Balkan region, that means also in the interstices of the sand, but the conclusion that the representatives of the genus Ingolfiella could be considered as typical members of the interstitial fauna cannot yet be drawn, because one species, Ingolfiella bathybia Hansen, is known from soft sediments of the deep sea. The individual species of the genus therefore differ greatly with regard to ecology.

The macrofauna living on coral reefs in the Maldives may be divided into four groups according to the mode of feeding:

I. Suspension feeders are the group most abundant on living coral heads. Some of these animals, insofar as they feed on zooplankton, represent direct competition for food with the corals; others, mainly pelecypods and sponges, feed on phytoplankton and fine sestion, which are not utilized by the corals.

Specialized adaptations to the existing environmental conditions are found among the forms which prefer to occupy the living part of the coral head. Thus, here are found not only the true boring forms, such as the boring mussel, Lithodomus, but also bivalves, including oysters, gastropods (Leptoconchus, /Dr. Gerlach has kindly informed me in a letter that the original identification was in error and that the form has since been identified as Magilopsis lamarcki Deshayes by Dr. R. T. Abbott, Academy of Natural Sciences of Philadelphia.--AJK/ Vermetus), barnacles (Pyrgoma), and decapod crustacea (Hapalocarcinus, Cryptochirus), which allow themselves to be surrounded by the growing coral and thus gain protection from predators.

Sessile animals, which also occur in hard bottom communities, colonize the dead base of the coral head: alcyonarians (Lobophytum, Sinularia, Cespitularia), zoantharians (Palythoa), sponges, tunicates, and bryozoans.

II. Detritus feeders and small predators occur, but are not excessively abundant in comparison with their numbers in algal zones and benthic communities. Detritus occurs on the coral reef only in relatively small amounts. Where the bottom is not covered with coral, small areas of pure calcareous sand are found. The floor of the atoll lagoon, under 30-40 m of water, is covered with calcareous sand which is also comparatively poor in organic debris. Only on the dead bases of the corals is there an algal growth worthy of mention as a food source for the microfauna. Representatives of the microfauna are mainly copepods, amphipods, isopods, tanaidaceans, ostracods, polychaetes, and nematodes.

To the group of detritus feeders and small predators belong a few brachyuran crabs and a few shrimps, which regularly live among the branches of the branching corals. Grazing gastropods are not common. An as yet unidentified holothurian sweeps with its tentacles the surface of all the dead coral heads. Serpent stars also occur regularly and are to be placed in this group of detritus feeders and small predators.

A number of coral fishes seek their food among the coral heads. Some are specialists, with elongate, pincer-like snouts, such as, according to the identifications by Herr Dr. Klausewitz (of Frankfurt), Forcipiger, Gomphosus, and Oxymonacanthus, and in addition many chaetodontids, acanthurids, and pomacentrids. Living directly in the coral heads are small fishes of the genera Gobiodon and Caracanthus. Chromis and Dascyllus, in contrast, use the branched corals as habitat and refuge, but seek their food in the plankton above the coral heads.

III. Predators have the smallest food sources on the coral heads and correspondingly are not abundant. Among the crustaceans, stomatopods and alpheids may be listed here, as well as predatory gastropods, polychaetes, and sea stars.

Whether nudibranchs and pycnogonids feed directly on the tissues of the coral polyps has not yet been determined. This could be observed in the case of one aberrant copepod /Xarifa/.

IV. Finally, fishes of the genus Kyphosus and above all parrot fishes (Scaridae) must be mentioned as the last group. With their strong jaws they bite off entire pieces of coral colonies and swallow with them the fauna living on them.

If we now ask which animals of the macrofauna stand in close ecological relation with the living coral reef as environment, an obvious case is that of the parrot fishes, which feed on pieces of coral, and that of those suspension feeders which let themselves become enclosed by the coral. To what extent the numerous "coral fishes" are adapted to the particular environmental conditions of the reef, or whether they also occur in comparable places where coral does not form the biotope, still remains open. The crabs of the genus Trapezia appear to prefer the coral biotope; whether this also is true of the other invertebrates found on the reef remains to be tested.

The aim of this investigation was to determine the place of the tropical coral reefs in the framework of marine environments. The opinion of Stephenson (1958) that the coral reef corresponds to the sublittoral algal region in the temperate zone was confirmed. The investigation of the microfauna shows especially that the coral reef can be included among the "phytal" environments. The common elements in the fauna of the coral reef and in algal regions are many, by contrast the forms especially adapted to life in close relation with corals are few, and it would not be quite justified to contrast at the same level the coral reef with the benthic and phytal biotopes.

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Qualitative description of the coral atoll ecosystem

by

F. R. Fosberg

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Qualitative Description of the Coral Atoll Ecosystem*

by F. R. Fosberg

A coral atoll may be described, in the briefest terms, as a cap of limestone of organic origin on a mountain on the floor of the ocean, rising to or only slightly above sea level. Some lie on shallow banks or continental shelves. The cap is commonly bowl-shaped on top with a ring-like ridge or reef surrounding a body of water termed a lagoon. Some parts of this reef may emerge above high tide level as islets. These may either be remnants of former higher reef levels or detrital accumulations. Much or all of the reef surface below mean low-tide level and down to depths where sun-light penetration is very attenuated is composed of communities of living plants and animals. In bulk, at least, these are mostly organisms that secrete limy skeletons. Accumulations of these skeletons make up, almost exclusively, the reefs and upper parts of the mountain down to the volcanic (or other) basement rock on which the reefs originally started to grow. The depth of this limestone is known for only a few atolls and may vary from at least 1400 meters to, probably, very much less.

The concept of the ecosystem, first proposed by Tansley (1935), is that of an interacting system composed of an environment and all of the organisms involved with it. It is normally an open system because there is a continuous, though variable, influx and loss of energy and material. Such a system is, of course, an abstraction constructed to facilitate understanding of the complex processes involved in a segment or class of segments of the biosphere. As such its extent is limited only by selection and definition of the segment or segments under study. Thus it may be varied, in different examples, from the smallest observable unit of environment in which organisms live to the entire world's biosphere as a whole with its total environment (Evans, 1956). As the ecosystem is only limited by the extent of the effective environment the maximum could be, theoretically, the entire universe. Practically, however, the definition will not ordinarily extend to the ultimate sources of energy, or even of material. It will be restricted to such extent as will best facilitate observation and understanding of the portion of nature under immediate study. This concept, of obvious and increasing utility but not too easy to handle, and never, apparently, used by its creator, has been, in recent years, adopted by a number of ecologists (e.g. Pitelka, 1955; Billings and Bliss, 1955; Oosting, 1956; Evans, 1956; Cain, 1956; Dansereau, 1957). No two have defined or formulated their ecosystems in exactly similar terms, nor is there any critical need, at this stage, to do so.

In this paper the <u>coral atoll ecosystem</u> will be described in terms of processes involving <u>transfer</u> or <u>transformation</u> of energy and material, with only incidental reference to the actual organisms involved in the system or to the physical structures found in the environment. It is

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recognized that in a complete account of such a system these aspects, also, would be described fully. For present purposes it may suffice to say that the biotic component of the system is composed of phytoplankton and zooplankton; free-living but bottom-dwelling animals and other heterotrophic organisms of many sorts; an enormous aggregation of sessile or fixed organisms representing most classes of algae, a few seed plants, and practically all phyla of invertebrate animals; and a diverse assortment of land animals and plants. Many of the marine organisms secrete skeletons of $CaCO_3$ which are added to the material of the substratum. This process forms a lattice-work of limestone in which free skeletons or loose fragments lodge. By several processes these may become bonded in such a way as to form a rather hard and resistant rock. This is built up in the form of a ridge or reef usually enclosing a shallow body of water or lagoon and rising variously to somewhat below, near, or just above high-tide level. This reef is ordinarily rather flat-topped, of varying width, with irregularities or islets extending above high-tide level. Waves commonly break on the outer margin and water flows from the sea to the lagoon and back to the sea over the flat or gently sloping reef surface or through gaps in it. The flow may be in and out with the tides, or in over the windward and out over the leeward sides. The islets are commonly composed in part or wholly of loose porous limestone debris and are mostly covered by vegetation that includes representatives of all major groups of land plants. The land faunas are made up of a large number of species of insects and other arthropods, worms, land molluscs, a few reptiles, some birds, and a few mammals, including rats and man. Larger islets may contain within their porous structures a body of fresh ground water floating on the underlying salt water and retarded by friction from free diffusion with it.

These atoll structures are found in most regions of the tropical and, more rarely, subtropical seas. Temperatures range generally between 75° and 85° F. or in full sun on land, higher, decreasing of course with increasing depth in the sea. General climates range from relatively dry, perhaps 600 mm. precipitation, to wet, 5000 mm. or more. The atolls are in trade wind, doldrum, and monsoon belts. Insolation is generally high, cloudiness low to moderate.

Most atolls are inhabited by human beings, some by relatively large populations. These exert a generally appreciable, often profound, influence on the functioning of the ecosystem. Of specific importance in this connection are the economic activities of planting coconuts, harvesting, drying, and exporting coconut meat, and importing in exchange various foods and other materials.

With this description of the general physical and biological situation, we may proceed to describe in more formal terms, the abstraction called the coral atoll ecosystem. This may be outlined as follows in 12 sections, lettered A to L.

A. Media.

B. Nourishment or inflow.

C. Production.

D. Transformation.

E. Decomposition.

F. Excretion.

G. Accumulation.

H. Turnover.

I. Miscellaneous other effects and processes.

J. Losses.

K. Balance.

L. Trends.

A. Media: The media in which the system exists are two--a layer of sea water and a superimposed layer of air. These, by the nature of the earth-system itself, are constantly changed by sea and air circulation. Through them, or by means of them, all exchange, gain and loss, of matter and energy takes place. These two media are the most universal and pervasive components of the ecosystem and at the same time its environment, influencing in some measure everything in the system.

B. Nourishment or inflow: Since the atoll is an open system there is a continuous addition of matter and energy in many forms. Fundamental, of course, is the daily increment of solar energy without which the system, in anything like its present form, could not exist. Its functioning is in almost every respect dependent on either photosynthetic or thermodynamic processes, which are dependent on constant addition of energy from the sun. The nourishment of organisms and the circulation of both air and water are important examples.

The energy of wind, mostly indirectly a form of solar energy, also exerts its force in various ways in the system. Most of this energy is received elsewhere and transported to the atoll.

The gravitational energy of both sun and moon contributes importantly to sea-water circulation in the form of tides. The movement of ground water in atoll islets also is influenced by tidal fluctuation.

Essential components of the media, such as O_2, N_2, H_2O, CO_2, as well as dissolved salts and suspended organic matter, and even living propagules and disseminules of organisms are continually renewed or carried into the system by air and ocean currents. Relative concentrations of the various components of the media are maintained at a rather constant level in this manner. The replenishment of the ground-water bodies in islets is dependent on incoming fresh water, mostly evaporated elsewhere and deposited as rain on the islets from wind-borne clouds. Surface currents, upwellings, trade-winds, monsoons and cyclonic storms are important aspects of the circulation patterns involved. The introduction into the system of phosphorus, on which organic activity is completely

dependent, is believed to be controlled to a considerable extent by upwellings of deep-sea water. One important route of transport of phosphorus from areas of upwelling to the atolls is by means of fish-eating birds and their young which deposit phosphates in their excreta within the area of the system. Essential mineral elements, nitrogen, and organic carbon are also brought in by the birds at the same time. Organic matter, in the form of drifting plankton, driftwood, and dead organisms, is brought to the atolls by currents. Currents also bring small amounts of mineral elements in the form of pumice as well as in solution. Volcanic ash arrives by way of winds, especially high altitude winds.

Finally, with changing patterns of human activity on atolls, increasing amounts of imported foods and other materials as well as alien organisms are introduced into the system. These introductions are effecting various rather profound changes in the equilibria and altering greatly the physical appearance of the atolls.

C. Production: The elaboration by plants of basic organic materials from elements and simple inorganic compounds is termed production, in an ecological sense. Such elaboration provides the fuel and building materials for all other life processes. The effective capacity of a system for production is called its productivity.

(1) The most obvious productive process is photosynthesis, by which carbohydrates are elaborated. Algae and green plants utilize CO_2, H_2O, and energy from sunlight for this purpose. Such algae occur as components of plankton, within the cells of corals and other coelenterates, fixed on the reef surfaces, terrestrially on soil and rocks, and epiphytically on tree trunks. Mosses are found in many terrestrial situations on the islets, as well as on tree trunks, especially where they are shaded. Ferns and psilopsids are common growing on land and epiphytic on trees. Seed plants grow principally on land, but some are epiphytic and a few are marine, growing in shallow lagoon situations on sandy bottoms. All of these groups, together, account for the origin of most of the carbohydrates used in the system.

(2) The other essential type of production is the fixation of atmospheric nitrogen--its oxidation and elaboration into simple compounds. It is well known that this fixation is accomplished by bacteria in the soil and in nodules on the roots of certain leguminous plants. Less well known, but possibly more important in the atoll system, is fixation of nitrogen by blue-green algae. This occurs on the soil surface and possibly in fresh and salt water. Much of the nitrogen available to atoll organisms is probably fixed within the system, but important quantities enter the system by way of birds, rain, and ocean currents.

D. Transformation: The alteration of primary and fabrication of secondary organic compounds: This function may be viewed as a succession of processes, mostly involving a break-down of organic compounds and their re-elaboration into more complex ones. Some of these are of an enormous order of complexity (e.g. nucleo-proteins).

(1) Autotrophic plants, in the nourishment of their own protoplasm and elaboration of stored material, cellulose, lignin and other materials,

carry out the first major step in a series of turnovers of the products of photosynthesis. Of course, additional inorganic materials are incorporated by this process and many of the elaborated compounds are infinitely more complex than the original carbohydrates produced by photosynthesis.

(2) Heterotrophic (parasitic and saprophytic) plants carry this process a step farther in utilizing already elaborated complex substances, as well as simpler materials derived from their hosts and organic substrata. Here may be mentioned the utilization of dissolved organic matter in the media by facultatively heterotrophic planktonic algae as discussed by Saunders (1957).

(3) Animals, feeding on plants in various ways, convert plant organic matter into animal organic matter. The principal classes of processes by which this is accomplished are as follows:

a. Eating of phytoplankton by zooplankton.

b. Utilization of material produced by zooxanthellae, by their coelenterate hosts.

c. Reef grazing and boring.

d. Eating of land plants by animals.

e. Eating of dead plant parts by animals.

f. Parasitism of plants by animals.

(4) Secondary conversion of animal matter to animal matter is accomplished as a result of three well-known classes of processes, namely:

a. Predation.

b. Parasitism.

c. Scavenging.

These are carried on in a great number of different ways by a large number of animals. Reef grazing and boring are important here, too.

(5) Reconversion of animal matter to plant matter is not as conspicuous a process, but is important nevertheless. There seem to be no insectivorous plants on atolls, so this reconversion is principally accomplished by bacteria and fungi living mostly on dead, and occasionally on living organic matter. It is an interesting question whether zooxanthellae utilize in any way the materials of their hosts' tissues.

E. <u>Decomposition</u> (usually but unfortunately termed "reduction"): The destruction of the elaborated organic compounds and reconversion back to simple inorganic compounds and relatively inert organic residues: Two main categories of processes are involved here.

(1) Physiological oxidation (inappropriately termed respiration by many plant physiologists), which is the oxidation of carbohydrate materials within living cells releasing the energy required for other life processes. This process goes on constantly in all living things.

(2) Non-biological oxidation, both by burning and by the slow oxidation of dead materials that normally takes place on exposure to atmospheric oxygen, aided or not by hydrolytic and catalytic action.

The principal products of both sorts of processes are CO_2 and H_2O, with, of course, inorganic and inert organic residues. Chemical energy is released and converted into other forms.

F. Excretion (within the system): The release of waste products and residues by organisms into the media:

(1) In water CO_2 and O_2 are released, as well as excreta and soluble metabolic wastes. Calcareous and siliceous skeletons and oily material remain after disintegration of organisms.

(2) On land, likewise, CO_2, H_2O, O_2, and metabolic wastes are released in solution in air or water. Guano and other excreta, as well as dead bodies and deciduous, caducous, or severed plant parts are deposited on the surface of the ground to decompose.

G. Accumulation: Storage of materials in unchanging or very slowly changing form, i.e. temporary withdrawal of material (and energy) from free circulation in the system.

(1) In bulk the limestone from calcareous skeletons of plants and animals represents the greatest and most important accumulation, the principal component of the atoll itself.

(2) Phosphatic residues, mainly calcium phosphates, are present as phosphate rock, components of soils, guano, and at least in some atolls (e.g. Washington Island) as a phosphatic mud or sludge on the lagoon bottom.

(3) Humus, both as raw humus in *Pisonia* forests, and as more stable humic residues in A_1 horizons of soils, plays an important part in the functioning of the system. The acid raw humus contributes to the formation of phosphate rock, and the soil humus helps to maintain the soil in condition to support growth of larger plants and micro-organisms. Humus, though relatively inert, is continually undergoing a slow oxidation.

(4) Slight accumulations of charcoal, metal oxides, silica and silicates occur where human activity is significant. Silica from sponge, radiolarian, and diatom skeletons also occurs in minute amounts as well as small quantities of silicates from floating pumice.

(5) Finally, fresh water, in the ground-water lens, as well as in the several states of soil water, may be regarded as a temporary accumulation.

The organic matter and other substances in living organisms represent a large total quantity but, as they are in a constant state of turnover, should probably not be classed as an accumulation.

These accumulations, along with the materials in solution in the media, may be regarded as the reservoirs of materials on which the other components may draw for nourishment.

H. Turnover of materials and energy: Categories D, E, and F, above are to be classed as turnover. In addition several more processes may be so regarded.

(1) Re-use of CO_2 released by oxidation.

(2) Re-use of O_2 released by photosynthesis.

(3) Re-use of H_2O released by metabolic and external chemical processes.

(4) Re-use of fixed nitrogen, both from metabolic wastes and from primary biological oxidation.

(5) Re-use of mineral nutrients released by excretion and breakdown of organic materials.

(6) Withdrawal from and return of various materials to media.

(7) Withdrawal from and return to accumulations.

I. Miscellaneous other effects and processes taking place within the system.

(1) Inhibition by salt (NaCl). The organic activity in terrestrial situations seems subject to a considerable inhibition by the salinity of the sea-water medium. This inhibition results from difference in osmotic pressure, the chemical effects of absorption of excess sodium and chlorine ions and consequent inhibition of absorption of others. The number of land organisms completely adapted to the normal salt concentration of the sea is limited. Hence establishment of immigrant organisms is severely limited, and many of those that become established function at below their optimum levels. Salt water enters the land environment as wind-borne spray, as storm waves, and by diffusion through the ground. The conspicuous nature of the limiting effects of salinity may be a reflection either of the small extent of the land habitat and consequently great exposure to salt or of its probable geologically recent origin that has allowed little time as yet for evolution of a special atoll biota.

(2) Effects of sea-air interface: Category 1 is really only one of the consequences of the fact that the land portion of this ecosystem is a thin lens inserted in the general sea-air interface. The distribution of many organisms, marine as well as land, is influenced by the character of this interface. Aeration, principal release of energy from insolation, frequently an abrupt break in temperature gradient, local high salt concentrations resulting from evaporation, solution and other forms of

erosion of limestone, and the shaping of the contours of vegetation and control of its composition are all consequences of the nature of this interface. Many more could be enumerated.

(3) Shelter effects. One of the reasons for the diversity of animal life in such an apparently simple environmental complex may be the variety of habitats resulting from the surface irregularity of the several substrata. The vegetation, the deeply pitted rock, the porous soil, and the intricate nature of the reef lattice provide shelter of various types for a large number of species of animals (and plants, too) that have widely differing requirements.

(4) Burrowing and turning over of soil by crabs is an important factor in the process of incorporating organic matter into the soil. Crab burrows are very common on many atolls, and fresh mineral soil is often piled or scattered around their entrances. The mechanical tilling of the soil in this manner has been compared to that accomplished by earthworms in other habitats. It doubtless is a process of great importance, though no careful assessment of its extent or effects has been made.

J. <u>Losses</u> (or excretion from the system):

<u>a</u>. Of the principal substances lost from the system the first three listed below are present in such constant proportions in the media outside the ecosystem that the losses may be considered as balanced almost exactly by inflow. The others are fluctuating quantities and there is no exact relation between inflow and loss.

(1) CO_2 carried away by winds and currents.

(2) O_2, carried away by winds and currents.

(3) N_2, carried away by winds and currents.

(4) Fresh water dispersed into media and carried away by winds and currents.

(5) Nitrates and organic N, carried away by currents.

(6) Phosphates, carried away by currents in solution and suspension.

(7) Other dissolved mineral substances, carried away by currents.

(8) $CaCO_3$ carried away by currents in solution and suspension.

(9) Plankton carried away by currents.

(10) Dead animals and plants and detached living fixed organisms carried away by currents and storms.

(11) Birds and other organisms which migrate.

(12) Export of copra.

(13) Export of pearl shell, etc.

b. Energy losses:

(1) Light, by reflection.

(2) Heat, by radiation and convection and carried by winds and currents.

(3) Chemical energy lost with elaborated materials.

K. Balance: The resultant of all of the factors at work on the segment of the universe (or of nature) occupied by the atoll ecosystem is the atoll itself. It may be thought of as a system in a state of dynamic equilibrium with a positive offset represented by the physical mass of the atoll with its associated biota, the total accumulation of organic and mineral matter over and above that of the normal media--air and seawater--that otherwise would occupy the space. All the characteristics described serve to set the system off from the surrounding undifferentiated media.

L. Trends: With such complexity it is hard to estimate trends, though it may be easy to discern them. Over very long periods the trend is obviously toward greater accumulation of material and probably toward increasing complexity. This trend usually seems directly related to slow subsidence of substratum on which the atoll is built, and may be expected to continue. On a shorter time scale it is possible to suggest that during periods of general or eustatic rise in sea level mass will increase, by addition of calcareous material in layers. Biotic complexity may at the same time decrease somewhat with tendency toward loss of land habitats. With fall in sea level the trends may be the opposite--loss of mass by erosion and gain in biota with appearance of land habitats, increased activity of sea birds, and especially the results of occupation by man. Presumably for about the last 3500 years the latter trend has been generally maintained. Whether or not the last few decades have witnessed a change in this trend is uncertain.

It seems clear that these major trends and fluctuations are controlled by factors external to the system. The ultimate control of sea level is as yet by no means clear. The variation in CO_2 content of the air has been suggested (Plass, 1956) as a factor that determines, or at least influences, world temperatures, evaporation of sea water, accumulation of ice, and consequent effects on sea level. It has been suggested that the recent apparent reversal of the fall of sea level may be due to the vastly accelerated industrial activity which pours great quantities of CO_2 into the atmosphere. If this is a valid assumption it seems reasonable to think that the present rise will continue, probably at an increasing rate. Thus a prediction might be made that the presently observed loss of land above water by erosion may be accelerated by a rise in sea level and consequent submergence of much or all of the land area of atolls. Such predictions, however, rest on very insecure bases at present.

On a still shorter time scale are the effects produced by the occupancy of the atolls by man, and especially modern man. These effects tend to be drastic as far as the land portions of the ecosystem are concerned but trends are as yet hard to isolate. Certainly the replacement

of the native vegetation by coconut plantations and the rise of the export of copra are notable and probably involve a complex of related or dependent effects. This change will probably continue but certainly at a decelerated rate, as land for expansion of plantations is becoming scarce. Augmentation of the land biota will probably continue as man's effect on the land environment continues. Pollution of lagoons will undoubtedly increase, with resulting encouragement to some organisms and ill effects on others. Fishing activities have tended to decrease with contact with civilization but this trend may probably be reversed and with use of such effective methods as dynamiting and poisoning the marine biotas may undergo considerable change. There has as yet been little attempt to measure the results of such factors so that here, as in other aspects of the system, estimation of trends is highly speculative. If such prediction is of interest, attention should be directed toward critical study of the details of the working of the system outlined above, to clarify it and fill in the parts that are at present inferential. It seems possible that if a firm understanding of this ecosystem is achieved it may be used as a model in terms of which to study other ecosystems.

Summary

The general physical and "physiological" framework of the coral atoll ecosystem has been outlined in terms of the media in which the system exists, nine categories of processes taking place within the system, the balance or dynamic equilibrium in the resultant structure brought about by these processes, and suggested trends in the state of this equilibrium. This highly generalized picture rests on a vast accumulation of facts and upon inferences drawn from them and from pertinent facts derived from study of related or analogous situations in other systems. It is hoped that this description may serve, until a better conception is devised, as a framework around which an understanding of this segment of nature may be built and as a guide for future research designed to clarify our knowledge and appreciation of coral atolls.

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ATOLL RESEARCH BULLETIN

No. 82

Heron Island, Capricorn Group, Australia

I. Description of Heron Island, by F. R. Fosberg

II. Vascular plants of Heron Island, by F. R. Fosberg and R. F. Thorne

III. Some observations on the Heron Island fauna, by J. M. Moulton

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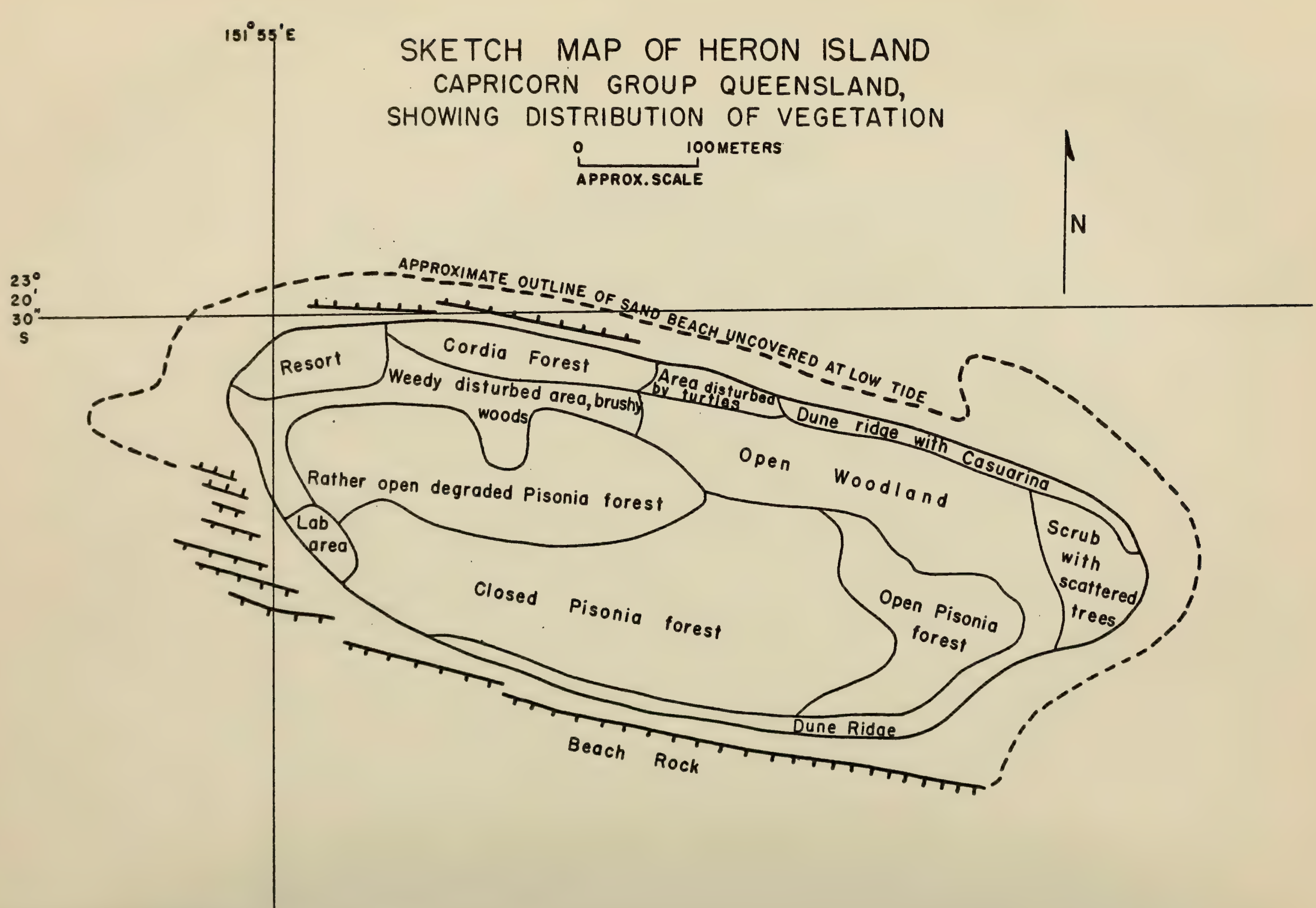
SKETCH MAP OF HERON ISLAND
CAPRICORN GROUP QUEENSLAND,
SHOWING DISTRIBUTION OF VEGETATION
0
100 METERS
APPROX. SCALE
N
151°55'E
23° 20' 30" S
APPROXIMATE OUTLINE OF SAND BEACH UNCOVERED AT LOW TIDE
Resort
Cordia Forest
Weedy disturbed area, brushy woods
Area disturbed by turtles
Dune ridge with Casuarina
Open Woodland
Rather open degraded Pisonia forest
Lab area
Closed Pisonia forest
Open Pisonia forest
Scrub with scattered trees
Dune Ridge
Beach Rock

I. Description of Heron Island

by

F. R. Fosberg

Heron Island, of the Capricorn Group, at the south end of the Great Barrier Reef, Queensland, Australia, is the site of the Marine Laboratory of the Great Barrier Reef Committee and also of a small resort. It is reached by a 4 to 5 hour launch ride from the port of Gladstone, Queensland.

J. B. Jukes (Narrative of the Surveying Voyage of H.M.S. Fly ... 1:6-9, 1847) gave a rather general account of the island, but paid particular attention to the beach rock, which he described in detail, with one of the earliest scientific speculations as to the origin of beach rock.

Heron Island is a small island, narrowly oblong or bullet shaped, about 45 acres in extent, formerly more than 100 acres, but said to have been largely swept away by a hurricane; it lies on the western end of an elongate reef, 5 miles long. This reef is separated from Wistari Reef by a narrow channel. It lies just inside the tropic of Capricorn at lat. 23°26' 30" S, long. 151°55' E.

The entire island is a sheet of flat coral sand mostly one to two meters above high tide level. The highest point (near the guest house) is 3.6 meters above high water (H. F. Manning, conversation, 1960). Along the south side is a dune ridge rising to perhaps 3 meters at most, above the general level of the island. Along the north side, at least in the eastern part, is a much lower dune ridge, at most a meter above the general level of the island. On the northeast corner is a notable sand apron on the reef below the beach.

A broad series of inclined beds of beachrock extends along the entire south coast, leaving the coast where the beach swings north and shortly disappearing. On the north coast a narrower strip starts at the curve in the west end and extends a short distance along the beach. Then, slightly offset to seaward, a very narrow, much eroded and pitted strip extends perhaps nearly half the length of the island. On the south side large numbers of slabs of beachrock have been torn loose and strewn along the upper part of the beach. These beds are said to be completely buried in sand at times. Toward shore, at the extreme west end, the beds on the south side become horizontal or even dip slightly toward shore. It is hard to tell whether these are normally exposed beds or have been laid bare by stripping off the upper beds for use as building stone for sea walls around the resort, as this activity was taking place during my visit. There is no other consolidated rock of any sort on the island.

The most notable vegetation type on the island is a low forest of Pisonia grandis, of trees perhaps 6 to 8, rarely 10 m. high. The pale gray or cream-colored elephantine trunks of this tree give a character to the landscape that is not easily forgotten. Scattered in this forest

are a few slender trees of Celtis paniculata, and, forming a very sparse lower story, shrubs of this species, Ficus opposita, and Pipturus argenteus which are 2 to 4 m. tall. A shrub or tall herb layer, locally quite prominent and almost continuous, is formed of Abutilon albescens and, in places, Euphorbia cyathophora. In open places is a mat of Wedelia biflora a meter or so thick. Where the Pisonia is thickest this shrub layer is sparse or lacking. Low herbs are almost lacking except for small patches of Stenotaphrum micranthum. At this time (October 1960), after a long dry spell, the Pisonia is largely leafless, especially the upper branches, and is just coming into flower. This relatively dense Pisonia forest occupies the central and western parts of the island, except for the south dune ridge and a strip along the north coast. It has been disturbed on the northwest corner by the building of the resort, and on the southwest by the building of the Marine Biological Laboratory and caretaker's house. Around the resort buildings as a precaution against storm damage, the upper branches of the Pisonia have been lopped off. Occasional fallen Pisonia trees are observed in the forest, mostly producing sprouts from their trunks.

East of the middle of the island, especially near the south side, the Pisonia forest is much more open. Here Celtis and Ficus are more common and larger, Pandanus is occasional, and the undergrowth of Abutilon and Wedelia is prominent, with occasional patches of Euphorbia cyathophora.

Along the north side, beginning at the resort, the forest, for a little distance in from the beach, is dominated by Cordia subcordata, rare or absent elsewhere on the island, with some Pisonia. This forest is not especially dense and has an undergrowth, in the spaces between the low-branching crowns of the Cordia, of Abutilon, Wedelia, and Euphorbia. Scaevola and Tournefortia are common in the edges along the beach, with a loose sod of Sporobolus virginicus at the top of the beach. Along the dune ridge on the south side is an irregular scrub forest of Pandanus, Casuarina, Tournefortia, and Scaevola. On the steep sand slopes above the beach Euphorbia ramosissima, Cakile, and Thuarea are common.

East of the Cordia forest is an area of open sand, much dug up by turtles, with scattered small Casuarina, Ficus, Scaevola, Pandanus, and Tournefortia. On the sand are Cakile, Wedelia, Lepturus (mostly dead at this season), Euphorbia eremophila, and Cassytha; the latter is parasitic on many of the other plants.

Eastward, and also east of the open Pisonia forest, the undergrowth becomes thicker and Pandanus becomes dominant in the tree layer. Celtis, Casuarina, Ficus, some Tournefortia and several dense patches of Suriana are also present. Scaevola and Wedelia are common, as well as Abutilon. A dead grass, probably Lepturus, and Euphorbia eremophila are common and Cassytha is very prominent, thinly covering the bushes and, locally, the ground.

At the east end is an irregular scrub 1 to 2 m. high, of Tournefortia and Scaevola, open in places, and with irregularly scattered small Casuarina trees. These trees are especially notable at the top of the beach and extend in a line on the low dunes along about half the north coast, and along the dune ridge on the south coast.

The vegetation of the island has a considerably disturbed look. Trails and roads have been cut into the Pisonia forest, and around the resort and the laboratory weeds are very abundant, especially Euphorbia cyathophora and Gnaphalium sp. Exotic plants have been set out in some abundance, but except for one small coconut tree, a few papayas, an oleander and one or two plumerias, most of them are still small.

Much of the appearance of disturbance comes from the burrowing of the wedge-tailed shearwaters or mutton-birds (Puffinus pacificus) which stir up the ground on most parts of the interior, and from the holes dug by green turtles (Chelonia mydas) and occasional loggerheads Thalassochelys caretta), which lay their eggs here, the former in great numbers. The ground around the margins of the eastern half of the island appears thoroughly churned up by their activities.

Before this visit I confidently anticipated finding phosphatic hardpan soils, with raw humus accumulalion, of the Jemo series,* similar to those found in the Central Pacific atolls. The conditions, as described, with Pisonia forest growing on coral sand, with abundant seabirds, seemed perfect for development of soils of this series. Actually, no phosphatic hardpan whatever was found, and only a very small patch showed any raw humus accumulation. This little area was, apparently by chance, not disturbed by shearwater burrows.

The absence of either phosphatic hardpan or an extensive raw humus layer was anticipated by Dr. W. Stephenson, of Brisbane University Zoology Department, in a conversation before the visit. He said that the constant stirring up of the soil by the shearwaters and mixing in of coral sand with the humus would probably prevent much accumulation of humus, and consequently, no phosphate rock formation could take place granting the correctness of my theory* on the process. His prediction was realized. The absence of phosphate rock in this area, where neutralization of the humic acidity by calcium carbonate sand is the rule, may possibly be regarded as further evidence for the soundness of the theory.

Nearby Mast Head Island is described (by H. F. Manning, conversation 1960) as having thick Pisonia forest also, but with abundant nesting of crested terns (Thalasseus bergii), the burrowing shearwaters being present but not predominating as at Heron Island (see Barrett, C., Nat. Geogr. Mag. 58: 354-384, 1930, who reports shearwaters there). It is suggested that a well-developed layer of raw humus overlying a bed of phosphatic hardpan will be found there. Phosphate has been exploited on Lady Elliot Island, 60 miles to the southeast of Heron Island, but no information is readily available as to its nature and origin.

J. B. Jukes (Narrative of the Surveying Voyage of H.M.S. Fly 1: 2, 1847), in his account of "First Bunker's Island", described what must certainly be Jemo soil as follows, "The materials of the encircling ridge were quite low, and thinly covered with vegetable soil among the trees; but the sand of the central plain, which was dark brown, was sufficiently

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* Fosberg, F. R., Soil Science, 78 : 99-107, 1954.

compact to be taken up in lumps, and a little underneath the surface it formed a kind of soft stone, with embedded fragments of coral. Some vegetable soil also was found, a few inches in thickness in some places, the result of the decomposition of vegetable matter and birds' dung." Saville-Kent, in The Great Barrier Reef of Australia... 101-102 /1893/, quoted Jukes' description of First Bunker's Island and assumed that it applied to Lady Elliott Island. However, Jukes (op. cit. opposite p. 3) illustrated Lady Elliott Island, referring to it by that name. From the location, as described in Jukes narrative, it seems more likely that First Bunker's Island was Lady Musgrave Island, a few miles to the north of Lady Elliott.

II. Vascular plants of Heron Island

by

F. R. Fosberg and R. F. Thorne

Through the courtesy of the Great Barrier Reef Committee, the authors were able to make collections of the vascular plants of Heron Island. These collections, made at different seasons, May and October, complement each other and it seems proper to make a combined report of them, and to include several records from the herbaria at Brisbane and Sydney. No systematic search for such records could be made, because of lack of time. Also added are sight records of species planted, mostly in pots, at the resort on the island.

A previous list, by W. D. K. MacGillivray and F. A. Rodway, based on collections made in 1927, published in the Report of the Great Barrier Reef Committee vol. III, pp. 58-63, 1931, has been included, showing some changes in the flora and some, also, in the nomenclature.

The Fosberg collections cited were made on October 5-6, 1960, and are deposited in the U. S. National Herbarium. Those of Thorne were made on May 8-9, 1960, and are in the Herbarium of the State University of Iowa, with a set at the Brisbane Herbarium. F. R. Fosberg is finally responsible for the determinations, though preliminary identifications of many of the specimens were made by S. F. Blake, L. S. Smith and R. F. Thorne.

Polypodiaceae

Polypodium punctatum (L.) Sw.
Pot plant seen by Fosberg, 1960.

Pinaceae

Pinus sp.
Very chlorotic seedlings seen by Fosberg, 1960.

Cupressaceae

Cupressus sempervirens L.?
Pot plant seen by Fosberg, 1960

Pandanaceae

Pandanus tectorius Park.
Fosberg 41302, 41325, 41326; Thorne 27210, 27215, 27248.
MacGillivray and Rodway 1931, p. 63, as *P. pedunculatus* R. Br.

This variable plant is, in Australia, commonly referred to *P. pedunculatus* R. Br., but seems to be well within the range of variation of the widespread Pacific strand species.

Gramineae

Cenchrus echinatus L.
Fosberg 41336; Thorne 27236.

Digitaria ciliaris (Retz.) Koel.
Fosberg 41310; Thorne 27234.

This species, the tropical representative of the common *D. sanguinalis*, has been called *D. adscendens* (HBK) Henr. by Henrard in his Monograph of the Genus *Digitaria*, but *Panicum ciliare* Retz. (1786), basionym for *D. ciliaris*, is earlier than *Panicum adscendens* HBK (1815), basionym *D. adscendens*.

Eleusine indica (L.) Gaertn.
Fosberg 41340; Thorne 27238
MacGillivray and Rodway 1931, p. 63.

Eragrostis cilianensis (All.) Lut.
Thorne 27212

Lepturus repens var. *subulatus* Fosb.
Fosberg 41583, 41343; Thorne 27216
MacGillivray and Rodway 1931, p. 63, as *L. repens* R. Br.

Spinifex hirsutus Labill.
Fosberg 41330; Thorne 27231

Sporobolus virginicus L.
Fosberg 41313; Thorne 27235
MacGillivray and Rodway 1931, p. 63.

Stenotaphrum micranthum (Desv.) Hubb.
Fosberg 41590, 41331
MacGillivray and Rodway 1931, p. 63, as *Stenotaphrum subulatum*.

Thuarea involuta (Forst.) R. & S.
Fosberg 41332; Thorne 27217
MacGillivray and Rodway 1931, p. 63 as *Thuarea sarmentosa* Pers.

Palmae

Cocos nucifera L.
Planted seedlings, seen by Fosberg, 1960

Araceae

Monstera deliciosa Lieberm.
Pot plant seen by Fosberg, 1960

Scindapsus aureus (Lind. & Andre) Engl.
Pot plant seen by Fosberg, 1960

Commelinaceae

Zebrina pendula Schnizel
Pot plant seen by Fosberg, 1960

Liliaceae

Hosta sp. ?
Pot plant seen by Fosberg, 1960

Sansevieria guineensis (Jacq.) Willd.
Pot plant seen by Fosberg, 1960

Marantaceae

Maranta arundinacea L. ?
Pot plant seen by Fosberg, 1960

Casuarinaceae

Casuarina equisetifolia var. incana Benth.
Fosberg 41301; Thorne 27219
MacGillivray and Rodway 1931, p. 63.

Ulmaceae

Celtis paniculata (Endl.) Planch.
Fosberg 41589, 41315; Thorne 27225

Moraceae

Ficus opposita Miq.
Fosberg 41584, 41591, 41318, 41324; Thorne 27227, 27240; Mary E. Gilham, s.n.; Sydney Univ. Biol. Soc. in 1948
MacGillivray and Rodway 1931, p. 63.

Ficus obliqua var. petiolaris (Benth.) Corner
MacGillivray and Rodway 1931, p. 63 (as F. platypoda var. petiolaris), described as having complex buttressed trunks.

Ficus sp.
Pot plant seen by Fosberg, 1960

Urticaceae

Pipturus argenteus (Forst.) Wedd.
Fosberg 41588; Thorne 27241
MacGillivray and Rodway 1931, p. 63

Proteaceae

Macadamia ternifolia F. v. M.
Pot plant seen by Fosberg, 1960

Polygonaceae

Rumex vesicarius L.
Cultivated, Fosberg 41341

The sepals lack the marginal nerve characteristic of the more commonly cultivated R. roseus.

Nyctaginaceae

Boerhavia repens L.
Fosberg 41309; Thorne 27230; Gillham in 1958; Sydn. Univ. Biol. Soc. in 1948. MacGillivray and Rodway 1931 p. 63, as B. diffusa L.

This strand species, taken in the broad sense, has usually been called B. diffusa L., but study of the Linnean specimens and of living material in Ceylon, type locality of B. diffusa, suggests that the pantropical plant is B. repens L.

Commicarpa chinensis (L.) Heim.
Fosberg 41316; Mauritzon in 1936

This species has usually been called Boerhavia repanda Willd. and the genus Commicarpa should probably be regarded as a section of Boerhavia. However, since Valeriana chinensis L., the earliest name, has not been transferred to Boerhavia, the above name is used for the time being.

Mirabilis Jalapa L.
Planted, seen by Fosberg, 1960

<u>Pisonia grandis</u> R. Br.
Fosberg 41591, 41303, 41317, 41319; Thorne 27233; Sydn. Univ. Biol. Soc. in 1948. MacGillivray and Rodway 1931, p. 63, as <u>P. brunoniana</u> Endl.

Amaranthaceae

<u>Amaranthus viridis</u> L.
Fosberg 41306; Thorne 27239

Portulacaceae

<u>Portulaca oleracea</u> L.
Fosberg 41334; Thorne 27242

Lauraceae

<u>Cassytha filiformia</u> L.
Fosberg 41311; Thorne 27220
MacGillivray and Rodway 1931, p. 63

Berberidaceae

<u>Nandina domestica</u> Thunb.
Pot plant seen by Fosberg, 1960

Cruciferae

<u>Cakile edentula</u> (Bigel.) Hook.
Fosberg 41300; Thorne 27218

<u>Coronopus didymus</u> (L.) J. E. Smith
Fosberg 41338; Thorne 27245

<u>Lepidium virginicum</u> L.
Fosberg 41305; Thorne 27223

<u>Sisymbrium orientale</u> L.
Fosberg 41304; Thorne 27246

Crassulaceae

<u>Kalanchoe</u> sp.?
Pot plant seen by Fosberg, 1960

Leguminosae

Cassia sp.?
Pot plant seen by Fosberg, 1960

Delonix regia (Bojer) Raf.
Planted seedling seen by Fosberg, 1960

Erythrina sp.
Pot plant seen by Fosberg, 1960

Samanea saman (Jacq.) Merr.
Planted seedling seen by Fosberg, 1960

Sophora tomentosa L.
Fosberg 21596

Zygophyllaceae

Tribulus cistoides L.
Fosberg 41308, 41321; Thorne 27229
MacGillivray and Rodway 1931, p. 62

Tropaeolaceae

Tropaeolum majus L.
Planted, seen by Fosberg, 1960

Simarubaceae

Suriana maritima L.
Fosberg 41323; Thorne 27228
MacGillivray and Rodway 1931 p. 62

Euphorbiaceae

Codiaeum variegatum (L.) Bl.
Pot plant seen by Fosberg, 1960

Euphorbia clutioides (Forst.f.) C. A. Gard.
Fosberg 41598, 41327; Thorne 27226
MacGillivray and Rodway 1931, p. 63, as E. eremophila A. Cunn.

Euphorbia cyathophora Murr.
Fosberg 41335; Thorne 27243

Euphorbia prostrata Ait.
Thorne 27222

Euphorbia pulcherrima Willd.
Pot plant seen by Fosberg, 1960

Euphorbia ramosissima H. & A. ?
Fosberg 41599, 41329; Thorne 27221
MacGillivray and Rodway 1931, p. 63, as E. atoto Forst.

It is by no means certain that this plant is really E. ramosissima, as the glands are greenish, rather than white, but it is certainly not E. atoto, and at least superficially resembles the widespread E. ramosissima.

Euphorbia tirucalli L.
Planted, seen by Fosberg, 1960

Malvaceae

Abutilon albescens Miq.
Fosberg 41587, 41320; Thorne 27244; Chadwick in 1951; Gillham in 1958.
MacGillivray and Rodway 1931, p. 61, as A. indicum G. Don.

This has been usually referred to A. indicum L. or A. indicum var. australiense Hochr, but is really much closer to A. asiaticum L. It should perhaps be regarded as a variety of the latter.

Caricaceae

Carica papaya L.
Planted seedlings seen by Fosberg, 1960

Cucurbitaceae

Cucurbita sp.
Planted, seen by Fosberg, 1960

Begoniaceae

Begonia sp.
Pot plant seen by Fosberg, 1960

Umbelliferae

Apium leptophyllum (Pers.) F.v.M.
Fosberg 41333

Plumbaginaceae

Limonium bonduelii (Lestib.) O.Ktze
Cultivated, Fosberg 41342

The leaves of this specimen are unusual for L. bonduelii, more nearly resembling those of L. brassicaefolia. The inflorescence, however, is that typical of L. bonduelii, with linear appendages at the nodes.

Apocynaceae

Nerium indicum Mill.
Planted, seen by Fosberg, 1960

Plumeria rubra L.
Planted, seen by Fosberg, 1960

Convolvulaceae

Ipomoea grandiflora Lam.
MacGillivray and Rodway 1931, pp. 60, 62 (on p. 60 in one paragraph said to have "a large purple flower and leaves often a foot in diameter;" and in a lower paragraph "its flowers were pure white, opening in the evening and closing after the sun rose in the morning," this latter on One Tree Island)

The white flowered species to which this name is commonly but incorrectly applied is Ipomoea tuba (Schlecht.) Don, which is frequently found on coral islands and does not have leaves up to a foot in diameter. I. grandiflora Lam. is probably Stictocardia tiliifolia, which has pale purple flowers and large leaves, but does not usually occur on atolls. Neither were seen by us on Heron Island, nor was any other morning glory.

Ipomoea pes-caprae (L.) Sweet
MacGillivray and Rodway 1931, p. 62

Not seen either by Thorne or Fosberg.

Boraginaceae

Cordia subcordata Lam.
Fosberg 41312; Thorne 27232
MacGillivray and Rodway 1931, p. 62

Tournefortia argentea L.f.
Fosberg 41593; Thorne 27224

Solanaceae

Petunia violacea Lindl.?
Planted, seen by Fosberg, 1960

Solanum lycopersicum L.
Planted, seen by Fosberg, 1960

Solanum nigrum L.
Fosberg 41307; Thorne 27211

Solanum pterocaulon Dunal
MacGillivray and Rodway 1931, p. 63

Labiatae

Salvia splendens Sellow ex R. & S.
Pot plant seen by Fosberg, 1960

Bignoniaceae

Jacaranda sp.
Pot plant seen by Fosberg, 1960

Goodeniaceae

Scaevola sericea Vahl
Fosberg 41595, 41597, 41314, 41322; Thorne 27213
MacGillivray and Rodway, 1931, p. 62, as S. koenigii Vahl.

Most plants seen are of the glabrous form, but with some variation between white and purple in flower color.

Scaevola sericea Vahl (pubescent form)
Fosberg 41328

One clump, represented by Fosberg 41328, is pubescent and has purple flowers.

Compositae

Conyza bonariensis (L.) Cronq.
Fosberg 41339; Thorne 27237

Gnaphalium luteo-album L.
Fosberg 41585
MacGillivray and Rodway 1931, p. 62

Sonchus oleraceus L.
Fosberg 41337

Wedelia biflora cf. var. canescens (Gaud.) Fosb.
Fosberg 41586, 41594; Thorne 27214
MacGillivray and Rodway 1931, p. 62, as W. biflora DC.

This is not exactly identical with the Guam material on which this variety is based, but until a detailed analysis of the complex is attempted, the canescent-leafed plants are probably best referred here.

III. Some observations on the Heron Island fauna

by

James M. Moulton*

A primary objective of recording underwater sound and of identifying biological sources of some of its components in the Heron Island area has been partially realized during October and November 1960, during which I have been a guest investigator at the Heron Island Marine Research Station, as well as a Fulbright scholar in the Department of Zoology at the University of Queensland. As elsewhere, the primary biological sources of underwater sound are fishes and invertebrates (chiefly alpheids and stomatopods); porpoises (*Tursiops*) have also been recorded.

The end of the yearly southward migration of whales past the Capricorn Islands occurred in early October. A single unidentified whale was seen thrashing the water west of Heron Island on October 4, and an adult and calf of the hump-backed whale (*Megaptera novaeangliae*) passed through the channel between Heron Island and Wistari Reef on October 7.

The wedge-tailed shearwaters (*Puffinus pacificus*) appeared on Heron Island on October 8 and the first calls were recognized during the evening of October 10. The bulk of them will have left the Island by the end of April (H. F. Manning conversation, 1960). According to Island residents, arrival was a bit earlier than usual this year. Numbers mounted rapidly to thousands, the birds settling and burrowing on frequently travelled ground as readily as in less accessible vegetated areas. The burrows are generally about three feet in length and the inner burrow is about 8 inches in diameter. The birds return to the Island at dusk each evening in a great flight; occasional stragglers come in later in the evening.

As of this date (November 17) eggs have not been laid in any burrows examined, and the paired birds frequently remain in the burrow during the day. The events of breeding behavior strikingly parallel those of Leach's petrel in the Bay of Fundy. Another parallel lies in the odor of the oil emitted during breeding from the male bird. The male mutton-bird emits this oil in copious amounts while preening the female.

Other birds abundant on the Island, but less closely observed, are noddy terns (*Anous* sp.) which have a large rookery in *Pisonia* trees, reef herons (*Demigretta sacra*), the nests of which are scattered through the noddy rookery in *Pisonia* and *Pandanus* trees, and silver gulls (*Larus novaehollandiae*) and crested terns (*Sterna bergii*) which frequent the beaches but probably do not nest on the Island. There is a white-breasted sea eagle's (*Haliaetus leucogaster*) nest in one of the tallest *Pisonia* trees. A number of other kinds of birds frequent the Island which has a rich bird fauna. Old reef heron nests are at times filled with partially gnawed *Pandanus* fruits, probably by the island rat *Rattus exulans*.

* Department of Biology
Bowdoin College
Brunswick, Maine

One of the most striking populations on the Island is one of Cerithium monifilerum Kiener, a small gastropod called a clusterwink. This snail behaves with a tidal rhythmicity of considerable interest. On the falling tide individuals of this species aggregate together in dense patches on a flat beachrock surface at the western end of the Island. The clusters are well-formed by the time the water depth is 14 inches; they disperse again on a rising tide when it reaches a depth of about 4 inches over a cluster. During high tide, the snails are dispersed rather evenly over the bottom. Clusters may number from 2 to over 1375 individuals; a few isolated individuals are noted between clusters at low tide, the mean size exceeding that of clustering individuals. The smallest individuals (generally under 6 mm.) do not cluster but are scattered in the sand. The composition of individual clusters varies from one low tide to the next as marking experiments have shown, and the clusters do not always form in the same places on consecutive tides. The clustering behavior is probably a mechanism for retaining moisture during low tide. Individuals in a cluster are in movement during exposure to the sun, so some turnover occurs. A small amount of coral sand is intermingled with the clusters, and a green alga often binds the clusters loosely together. A cluster removed to the laboratory disperses, and individuals move about separately in shallow pans and aquaria.

The mechanisms involved here are of considerable interest; it would, for example, be of interest to remove some of these animals to other areas for a study of relation of behavior to tidal rhythms. As the amount of silt and algal scum varies on different beachrock areas, the populations of Cerithium will vary; increasing surface accumulation decreases Cerithium populations. The clusters are most strikingly formed on flat, denuded beachrock.

Turtles have been late in arriving this year, according to Island residents. The first track was formed on the night of November 11 - 12, and a few turtles have come up since then. As I write this, I have just come from the digging site of a large loggerhead preparing to deposit her eggs within a score of yards of the nearest buildings of the Island resort. While the turtles laying on Heron Island are the green (Chelonia mydas) and loggerhead (Thalassochylys caretta) turtles, a small hawksbill was captured on the reef in mid-October. The latter is said to be uncommon in the vicinity of Heron Island.

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No. 83

Notes on some of the Seychelles Islands, Indian Ocean

by

C. J. Piggott

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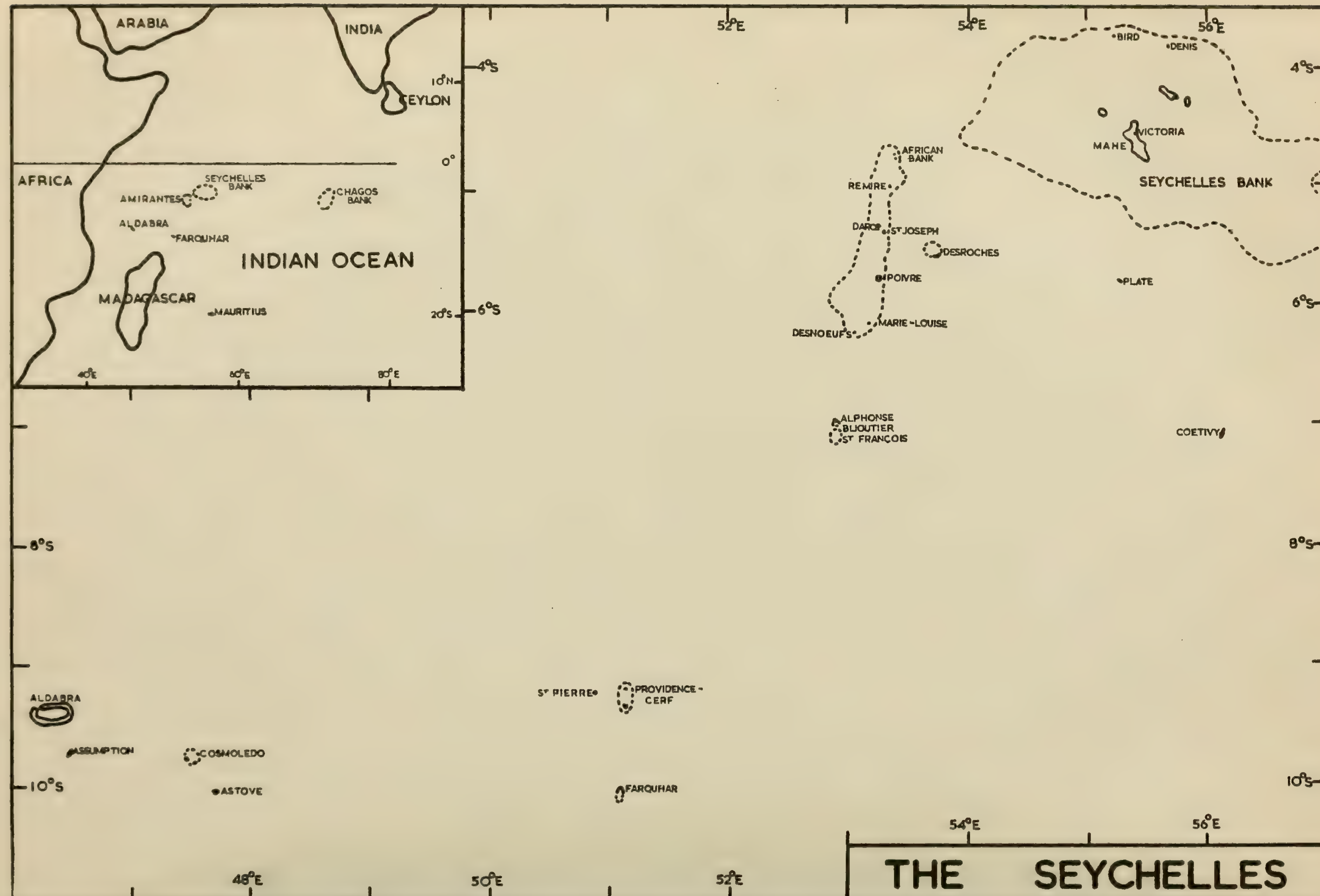
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BIRD
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REMIRE
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ST JOSEPH
DESROCHES
POIVRE
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MARIE-LOUISE
DESNOEUFS
ALPHONSE
BIJOUTIER
ST FRANÇOIS
COETIVY
ALDABRA
ST PIERRE
PROVIDENCE-CERF
ASSUMPTION
COSMOLEDO
ASTOVE
FARQUHAR
THE SEYCHELLES

Notes on some of the Seychelles Islands, Indian Ocean

by

C. J. Piggott

Introduction

The Seychelles are a group of islands in the western Indian Ocean (see map), under British Sovereignty. They are scattered over an area of about 150 thousand square miles but the actual land area is only about 100 square miles, 87 of which are accounted for by mountainous granitic islands at the administrative centre of the group, where is the capital, Victoria. Although these are beyond the scope of this paper the economic status of the 'Outer Islands' is dependant on the reservoir of labour and the facilities of exporting produce, which exist on the granitic islands.

The Seychelles Bank is, in effect, a fringing reef of the compact group of granitic islands but is unusually deep over most of this area. The rim is however relatively shallow and at a number of points near enough to the surface to become a danger to navigation. A slight drop in sea level would expose several islands which now only exist as shoals. In two places the bank rises above the surface, giving the islands of Denis and Bird, which are typical of sand cays normally found on atoll rims and are included in this discussion.

A second major bank in the Seychelles, the Amirantes, carries a number of reef islands and atolls, ten in all, with several shoals and submerged reefs. All the other Outer Islands are on separate bases.

Most of the common types of 'coral' island are represented in Seychelles and rough classification based on their morphology is:

Sand Cays (not on atolls, with no sign of recent uplift): Denis; Bird; Daros; Platte; Coetivy; African Banks; Etoile; Boudeuse.

Uplifted Sand Cays (not on atolls): Desnoeufs; Remire; Marie-Louise.

Atolls (with associated sand cays but not uplifted): Farquhar; Providence-Cerf; Alphonse; Bijoutier-St. Francois; Poivre; St. Joseph; Desroches.

Raised Reefs (no lagoon): St. Pierre; Assumption.

Raised Reefs on Raised Atolls (with lagoon): Aldabra; Cosmoledo; Astove.

Islands of the first three groups have an agricultural potential but those in the last two are of little value unless guano is present. Most are privately owned but a few remain as government property and are leased to suitable companies.

The past history of the islands is obscure, although it is known that the Amirantes were discovered by Vasco da Gama on his second voyage of exploration in 1502 and Farquhar was probably seen by Juan de Nova in 1503. Previous knowledge of the islands by Arab and Indian traders is not impossible. They were not charted accurately, however, until 1825 and it was not until the end of the 19th century that they began to have any economic importance. None of the islands have been permanently inhabited. In the early days of exploitation, fishing camps were established and it was probable that guano was discovered at the same time. Similarly, it would be noticed that some islands were suitable for cultivation.

It is proposed in this paper to discuss four typical islands in detail; Alphonse, St. Pierre, Astove and Desnoeufs with a final section dealing with variations to be found on the other islands. Firstly however it is necessary to give a brief reference to the meagre scientific work which has been carried out and to describe the guano and copra industries on which the economy of the islands depends. Not mentioned later is fishing which has, for many years, promised a great future but has never lived up to its promise. Large catches are obtainable near the islands and there is a small trade in salt fish, especially from Aldabra and Cosmoledo. Unfortunately, storage and marketing facilities have always been troublesome and, although a considerable variety of species can be caught and prepared, the export has been dropping and in 1960 only 82 tons were shipped. Without refrigeration and good transport facilities it is unlikely that a valuable market will be developed and it is somewhat galling that the Japanese find fishing in the waters between the islands quite profitable.

Previous Scientific Work

Although brief mentions of the islands had been made previously e.g. in Bojer's 'Hortus Mauritianus', in Coppinger's 'Cruise of the Alert' and in Linell's paper on insects (17), the first detailed study was carried out by the two 'Percy Sladen' Expeditions in 1905 and 1908, which have been reported on by Gardiner and Cooper (1 & 2) and by a series of papers up to 1936 in the Transactions of the Linnean Society, covering mainly the botanical and zoological features. Special mention must be made of two papers by Fryer (3,4) which show the results of detailed research rather than the recording, collecting and systematic work which characterized these expeditions.

Further information, mainly agricultural, has been given by Dupont (5,6) and recently by Piggott (7). Other recent papers of interest are Vesey-FitzGerald on ecology (8) and bird life (9,10) and Ridley and Percy on birds (11,12). Finally a valuable memoir on the geology and guano reserves of the islands is in preparation by Baker (13).

Climate

It is convenient to mention here the climate of the islands. This is dominated by the south-east monsoon of the Indian Ocean which blows strongly and steadily from about the end of April to November and, during

which, the rainfall is negligible. This period has hot almost cloudless days with an average shade temperature of about 83°F. The north-west monsoon is much weaker and its effect decreases westwards. At this time the islands experience variable winds and somewhat cloudy conditions. Rainfall is usually torrential but thunder-storms are rare. Although records are scarce it seems that islands eastward of the Amirantes have an annual fall of some 55 inches but this decreases sharply eastwards and on Aldabra it is probably only 15 inches. During the north-west monsoon temperatures are slightly higher, as is the humidity, and without wind the climate can become most trying. It is during this season that cyclonic disturbances occur to the south and the more southerly islands have occasionally suffered severely from their effects.

Guano

Many of the islands had workable guano deposits and, on several, guano formation was continuing when exploitation commenced. The total quantity which has been exported probably approaches half a million tons but relatively little remains now. Guano working started late in the 19th century, peak production being between 1906 and 1930, and still continues, on a reduced scale, on St. Pierre and Astove. The material was found on all types of island and was usually worked by very primitive methods which were, however, profitable. Human activity disturbed the enormous colonies of seabirds and they never returned in quantity and it is only on Desnoeufs and one or two minor atoll islands that guano formation continues. Another loss was the natural vegetation which had to be destroyed before the guano could be scraped up. Except on those islands where coconut planting was possible, the flora, after working ceased, was very limited and the species are now few and of little value.

Coconut Industry

Some coconut planting must have started in the 1870's or so, for it has been reported (1) that the plantation on Farquhar was destroyed by a cyclone in 1893 whilst a photograph in the same paper shows mature palms on Poivre in 1905. Now, all suitable land, and much unsuitable, is planted to coconuts under plantation conditions with little competition from other plants. In the early years yields were poor and not until about 1910 was it realized that special methods of planting and cultivation were necessary on these soils which are inherently infertile and have a low water holding capacity. Since then, yields have improved greatly and compare favourably with those obtained in other parts of the world. As an indication of these yields Alphonse gives annually 2,800 nuts per acre, with the Outer Island average being 1,861. On the granitic islands the yield is only 1,463 nuts per acre per year.

The agricultural technique necessary to produce these yields are (a) good spacing, (b) planting in holes dug to the water table and filled with organic debris, (c) keeping a free root passage to the water table by making holes, similar to the planting holes, close to the palm every 10 years or so, (d) utilizing all trash and husk as mulch, or organic manure and (e) slashing all weeds at least once every year.

The nuts mature on the palm; are collected after falling and converted to copra immediately. After initial rapid drying in locally designed hot air dryers, usually fired by shell and a few husks, the copra is finally sundried to a low moisture content. It is of high quality and stores well, as it must, for local schooners only call at the islands four times a year and there is often several months delay after this before final export.

Pests have been important on most islands especially the scale insects, and their biological control by coccinelids has been spectacular (14). Damage by Oryctes monoceros can be severe but many islands are free of this pest and stringent precautions are taken to prevent its entry. Finally, Poivre and Daros have recently suffered from an infestation by a long-tailed mealy bug, Pseudococcus adonidum, and attempts are being made at present to bring it under control by biological means.

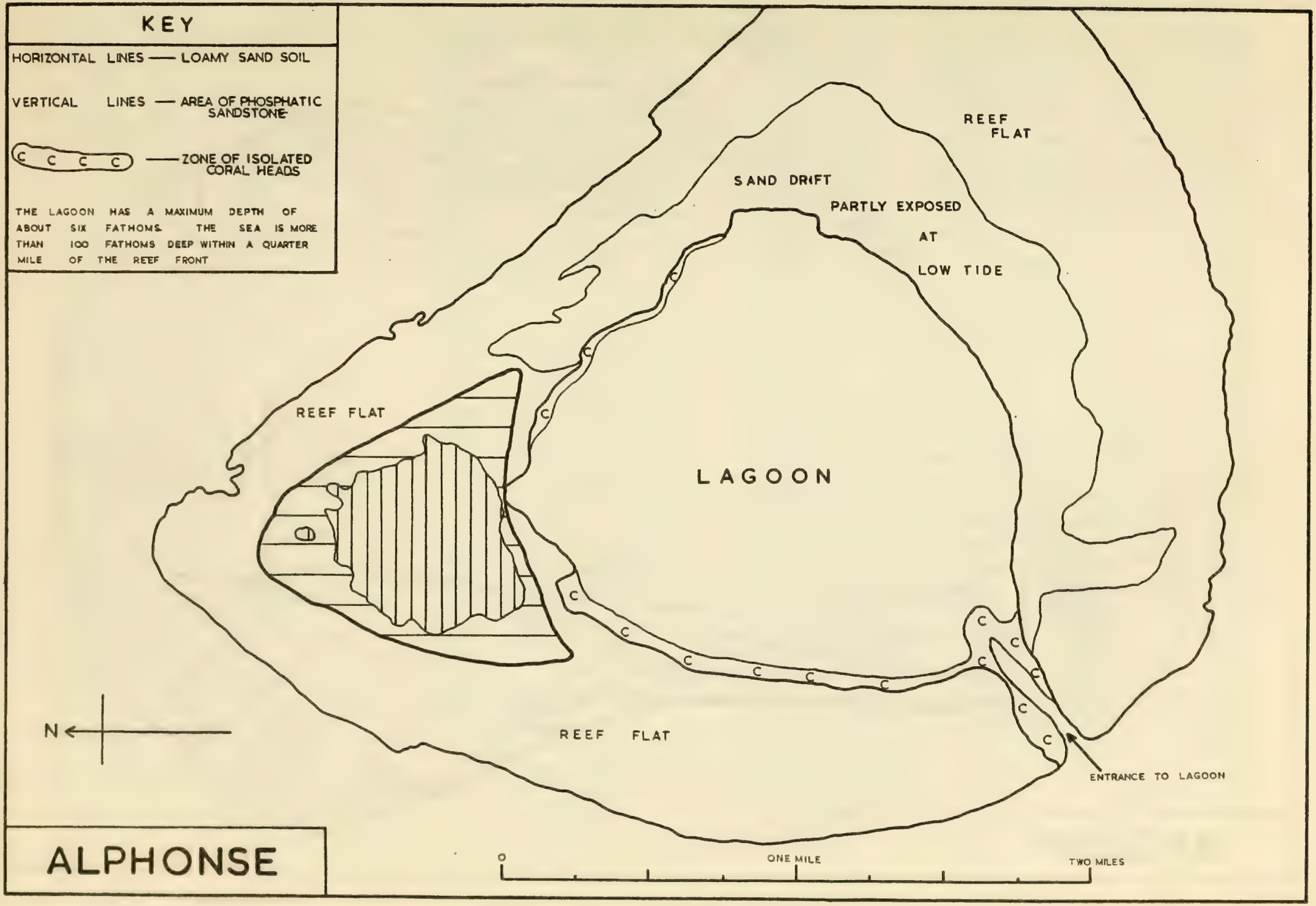
Representative Islands

ALPHONSE

This is a sand cay of some 450 acres, the only land on the rim of a small circular atoll some two miles in circumference (see map). There is a surf-boat passage into the lagoon, which is 15-20 feet deep in most places although there are considerable sand drifts near the reef which are exposed at low tide and emergence of more land is likely. The external reef slope is steep into deep water and the anchorage for schooners is not good, especially during the south-east monsoon.

The shape of the island, roughly an equilateral triangle, is somewhat unusual for an atoll cay but it does confer many advantages, not the least being a large fresh water storage capacity. As is common, the periphery of the island is somewhat higher than the centre but by no more than two or three feet. Beach sandstone is very uncommon with only a small patch near the middle of the lagoon shore. The centre of the island is, however, occupied by a massive layer of phosphatic sandstone which is, in places, over seven feet thick. Around this sandstone and, as far as it is possible to determine, below, the island is composed of uniform coarse sand with gravel only occuring at the points of the triangle.

The soil developed on the sand is a typical Shioya loamy sand (15) with Shioya sand near the coast. Owing to the agricultural development, undisturbed profiles are virtually nonexistant. It is probable that the sandstone in the centre of the island is part of a variant of Fosberg's Jemo Series (16) but with a much thicker than usual cemented layer. Guano, the surface horizon, has been exported but remnants show between 25% and 30% total P_2O_5 and its pH (colorimetric) varies between 5.7 and 7.0. The phosphate content of the rock slowly decreases downwards but the pH increases to about 8.0 within a fraction of an inch below the rock surface. The rock is pervious, and water can percolate down occasional cracks, but it forms an effective barrier to root penetration. There is no rock below the water table, which is at roughly the same level as in the sand.


KEY
HORIZONTAL LINES — LOAMY SAND SOIL
VERTICAL LINES — AREA OF PHOSPHATIC SANDSTONE
C C C C — ZONE OF ISOLATED CORAL HEADS
THE LAGOON HAS A MAXIMUM DEPTH OF ABOUT SIX FATHOMS. THE SEA IS MORE THAN 100 FATHOMS DEEP WITHIN A QUARTER MILE OF THE REEF FRONT
REEF FLAT
SAND DRIFT
PARTLY EXPOSED AT LOW TIDE
LAGOON
REEF FLAT
REEF FLAT
ENTRANCE TO LAGOON
N
0
ONE MILE
TWO MILES
ALPHONSE

Although the wave action does not penetrate more than 30 yards inland, the inter-connecting caverns honeycomb the whole island and at the water table is, invariably, sea water. At one time the whole island was covered with guano and this has resulted in a considerable phosphatisation of both the coral rock and any drifts of sand which were present on uplift. At least 150,000 tons of high grade guano have been removed whilst in recent years the rock has been crushed and mixed with the guano giving a standard export grade of product with 22.5% P_2O_5 at a low moisture content. Small deposits of guano are still being found in caverns where it has been washed by rain.

Prior to guano exploitation the island had a mixed vegetation with a bank of *Pemphis acidula* along the coast and, behind, a scrub with *Pisonia grandis*, *Cerbera odollam* and *Hibiscus* spp. predominating (4). Now it is almost a desert. On the east coast a few scattered *Pemphis* bushes still exist whilst only two, extremely battered specimens of *Pisonia* have been left in the centre of the island. Of the herbs which survive on the remains of the soil, *Stachytarpheta indica* is the most common. A surprizing introduction which appears to be establishing itself is *Gaillardia pulchella* and this relieves the monotony of the colouring during the dry season. On the blowhole 'dunes' there is a thick mat of *Sporobolus virginicus*. Around the settlement several exotics have established themselves including *Datura stramonium*, *Asystasia gangetica*, sisal and a few pawpaws and bananas. Nearby, a partial windbreak of *Casuarina equisetifolia* has been planted and this, surprisingly, is thriving and spreading.

The island has, obviously, no agriculture potential and no food crops are grown. It can only be hoped that, when guano exploitation has finished, the birds will return or the *Casuarina* spread over the island. Otherwise it is likely to remain a desert.

ASTOVE

Astove (see map) has been classified as a raised atoll but it is not impossible that the shallow lagoon has been formed by solution for, as suggested by Fryer (4), it is rapidly widening and deepening. This lagoon, which is only about ten feet deep at the maximum, has an entrance, some 200 yards wide, only about two feet deep at low tide. The lagoon water has a high concentration of suspended calcium carbonate which is flushed out on a falling tide, and this gives the water an opacity similar to that of milk. Other than the single entrance, the lagoon is land locked. The atoll is surrounded by a fringing reef some 200 yards wide with an exceptionally steep outer slope, the water being over 100 fathoms within 100 yards of the reef front.

The maximum elevation of the reef rock is some 15 feet but, owing the rapidity of solution, the actual uplift must have been much greater. The reef rock is only exposed in quantity on the west limb of the island; the base of the remainder being somewhat lower and composed mainly of gravelly reef debris. On this debris has been developed a line of coastal sand dunes over fifty feet high and drift from these has given a shallow

cover to the gravel. Similar, but much lower, dunes have been formed on the leeward lagoon shore. All the dunes appear to be stable at the present time, although there is some superficial movement of sand grains during high winds, and they have a fairly good plant cover. The presence of dunes on the five southerly island groups only, indicates that the effects of cyclonic disturbances are important in their formation.

As on St. Pierre, the reef rock of Astove is cavernous and large quantities of the surface guano were washed into these and redistributed by the sea water. Although sporadic workings have taken place there probably remains an exportable weight of guano hidden in undiscovered caves. There remains little trace of the original vegetation in this rock area but trees of Pisonia grandis still occur, with occasional Sideroxylon inerme. More important is a herb 'mat', which thrives where there is any soil remaining, with Plumbago aphylla predominating and including Dactyloctenium pilosum and Stachytarpheta spp. Sisal and wild cotton also exist on the very thin soil.

On the western limb, both coastal sandy areas have been planted with coconuts which are, unfortunately, not thriving. Owing to the height of the ground surface above the water table the palms have difficulty in obtaining moisture during the dry season and they suffer badly from wind damage. Admittedly, there is no wind break and the palms are growing on exceedingly rocky land at the edge of the reef rock area and it is possible that these are tapping water supplies and nutrients from the caverns below. There is certainly no soil on the rocks.

The soil of the dunes approximates to the Shioya Sand (15) but should probably be in a 'series' of its own, as the grain size is remarkably uniform and the agricultural potential is low owing to the limited water retention. The gravel flats have a very gravelly variant of the Shioya Loamy Sand, there being a considerable variation in the textural profile with depth owing to an admixture of wind blown material. This soil is probably suitable for palms as it can retain a reasonable quantity of water but little planting has been attempted owing to the absence of a windbreak - the dunes themselves not being effective enough. Excellent crops of maize have been obtained occasionally however.

The natural vegetation of these dunes appears to be a mat of Sporobolus virginicus in the spray zone and above this desiccated wind-moulded shrubs of Suriana maritima. Where the exposure is less, Scaevola sericea and Tournefortia argentea come in with very occasional Pisonia grandis. Clumps of Fimbristylis form a scattered ground cover whilst Cassytha filiformis is common, climbing over all and sundry. On the gravel flats the predominant vegetation is a mixture of drought resistant grass species including Stenotaphrum complanatum. Near the lagoon Pemphis acidula occurs and there are occasional specimens of Avicenia marina; but these do not thrive in the milky water.

The potential of this island has never been exploited; the main interest in the past being guano which can now only be collected as a sideline. A little commercial fishing has hardly paid its way whilst interest in agriculture has only been sporadic. Coconut planting is possible, if suitable windbreaks are established first, on much of the sand

and gravel soil whilst annual crops such as maize will give good yields if properly looked after. The only real problem is the chance of a cyclone which could destroy all the work.

DESNOEUFS

This uplifted sand cay, of some 86 acres only, is the only example of a virtually untouched island in the group. It is nearly circular with a maximum height of about 18 feet but, as usual, is saucer shaped, the centre being 7 feet above high water. There is no lagoon, only a fringing reef, and the reef flat is narrow. On top of this are many irregular blocks of beach sandstone which have been broken away from the more continuous sheets on the island edge. The landing, even by surf boat, is extremely hazardous and this is one of the reasons why the island has not been exploited.

The geologic structure is complicated. From the air can be seen a series of white concentric rings which stand out against the brown and green of the soil and vegetation. Ground inspection shows these to be outcrops of apparently typical beach sandstone with an angle of dip approximating to 25°. Between them is sand. This sandstone is only formed by precipitation of calcium carbonate, when a saturated solution comes into contact with a saline groundwater and must indicate previous coastlines of the island. It is probable that each outcrop coincides with a different stage of uplift, the older one having lost much material by solution. The original stable sand cay was, therefore, about 100 yards in diameter. Outside the visible sandstone outcrops is a coastal sand-dune, formed from reef debris carried inland under storm conditions. Doubtless this covers further outcrops for similar intact sandstone is found exposed at the boulder zone. It is of interest that a similar structure is found on Marie Louise, only seven miles away, but there it is obscured by the luxuriant vegetation.

The vegetation on Desnoeufs is not luxuriant. It is depressed as the result of the presence of numerous sea birds. Ridley (11) estimated that a million and a quarter breeding pairs of terns congregate there in addition to numerous boobies and 'fouquets' (Procellaria pacifica hamiltoni). In the past an export of preserved egg yolk was permitted and in one season over 1,500 gallons were shipped. Nowadays the island is a bird sanctuary and egg collection is only allowed every alternate year, when over one and half million eggs are sent to the central island where they form a major item in the diet. Surprisingly, this has made little or no difference to the total population. There is a fairly thick layer of guano on the ground and its formation is continuing. At the same time the sand and the beach sandstone are becoming phosphatized.

As can be expected, only a few plant species can survive the steady rain of bird excreta during the dry season. Even the normal coastal scrub of Scaevola sericea is limited to half-a-dozen stunted bushes. An unidentified tufted grass exists on part of the coastal dune but the remainder of the vegetation is limited to either short lived annual species which can seed before the bird concentration becomes too great

or to very tolerant perenials. The commonest plant is Stachytarpheta but the total number of species is only about ten. There are certainly no trees, with the exception of a small clump of some twenty coconuts which are struggling to survive in the centre of the island.

Possibly a little of the guano has been exported as there is some evidence of workings but the quantity must have been very small. Again an attempt has been made to plant coconuts as sites of planting holes can be seen on the aerial photographs (but not on the ground). Whether these holes were once planted is impossible to determine but certainly only the palms mentioned above survive.

THE OTHER ISLANDS

The geological classification of the other islands has been given previously. Within each group the islands are superficially similar but differ greatly in detail. The larger sand cays are all used for coconut production as individual plantations and all but the most youthful have some remaining guano and phosphatic sandstone. Bird and Goelette on Farquhar atoll, are the only large cays with a significant sea bird population. The former was the site of a very large ternery fifty years ago but exploitation of guano and the beginning of agricultural development caused the disappearance of birds from all but a few acres on a very recent sand spit. The very small cays have not been exploited and are still nesting sites for some birds, and will be valuable if they increase in size by accretion of sand. The biggest sand cay is Coetivy with an area of over $3\frac{1}{2}$ square miles, the smallest cultivated one being Bijoutier which is only two acres. The atoll islands are similar to the sand cays but the adjacent lagoons vary considerably in depth. For example, it is only possible to enter St. Joseph lagoon by dragging a boat over the reef but the lagoon is deep and provides excellent fishing; Farquhar atoll has a deep water entrance and schooners can moor against a short pier on the main island in sheltered water but the lagoon is fairly shallow and abounds in coral 'heads'; whilst Desroches is on a submerged reef which can only be discovered by sounding, its lagoon having a maximum depth of 17 fathoms.

The raised atolls and reefs are scientifically more interesting but economically of little value. Aldabra, for example, is one of the two remaining island groups in the world inhabited by species of Giant Tortoises, (Testudo gigantea), the other being Galapagos, but, apart from mangrove poles and its use as a base for fishing and catching turtles, it has no immediate value although the land area is considerable. The same applies to Assumption and Cosmoledo, although guano was exported from them in quantity once. Certainly, where there is no soil there can be little agriculture.

Summary

The Seychelles Outer Islands show features common to many atoll groups of the tropics but the variations in relative uplift are large for such a small area. The natural fauna and flora have been modified by the guano exploitation and coconut plantations.

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Atoll News and Comments

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Atoll News and Comment

Although the intention was to include, in each issue of the Bulletin, a short section on items of current interest, various circumstances made it inconvenient to do so in the last several issues. Hence the present article is more extensive than intended and some of the items are decidedly out of date. It is hoped that this will not occur in the future. It is also hoped that readers will continue to send in current items of interest to those concerned with coral atolls.

The present issue of the Atoll Research Bulletin has been seriously delayed and, consequently, some of the articles have been on hand for a deplorably long time. Apologies are hereby offered to the authors.

Recent and current investigations

Christmas Island:

Considerable work is either in progress or planned on Christmas Island, taking advantage of its status as an atomic proving ground, with attendant ease in communication and availability of facilities. Dr. David I. Blumenstock made a fairly extensive visit there in June 1960, studying weather phenomena and hydrography. He plans another visit as soon as circumstances permit. Dr. Philip Helfrich of the University of Hawaii, makes frequent visits, working on marine biological problems. Mr. Philip Ashmole, of the Edward Grey Institute, Oxford University, is planning an extended expedition to Christmas Island in 1962 to study the breeding cycles of sooty terns and other sea birds and to relate them to seasonal fluctuations of plankton abundance in the waters around the island.

Leeward Hawaiian Islands:

Prof. M. D. F. Udvardy, of the Zoology Department, University of British Columbia, writes of an 8 day expedition to Laysan Island in July 1959. The party included, in addition to himself, George D. Butler, Jr., Richard E. Warner, and Charles Daniel. Investigations included work on entomology, observations on behavior and a census of monk seals, observations on Laysan duck and finch, shearwaters and other birds, weather observations, collection of the flora, and vegetation mapping. Observations were made in relation to the nature and development of biotic communities. It is of interest that Dr. Udvardy seems to concur with our idea that the simplicity of atoll biota may help in understanding biotic communities generally. We are looking forward with great interest to the series of papers planned to report the results of this expedition.

As a continuation of the above mentioned observations, a 10-man expedition visited Laysan following the Tenth Pacific Science Congress, September 1961. Participants were Dr. A. Starker Leopold, Dr. Miklos D. F. Udvardy, Dr. Robert L. Usinger, Dr. George D. Butler, Jr., Dr. Charles H. Lamoureux, Dr. Martin Vitousek, Mr. Edward C. Jestes, Mr. Richard E. Warner, Mr. David H. Woodside and Mr. Ronald L. Walker. In addition to a week on Laysan, short visits were made to Kure and French Frigate Shoal. Transportation was furnished by the U. S. Coast Guard.

Midway Island--albatrosses and the jet age:

We can report that, as of October 2, 1961, the threatened slaughter of gooney birds on Midway Island by the U. S. Navy has not yet taken place. When the plan to eliminate these albatrosses because of the hazard of collisions between them and planes was publicized in 1959 such a protest arose from organizations and individuals that the action was deferred. Investigations were carried out to see if the birds could not be frightened or coaxed away from the runways.

A number of ideas were tried out, including the use of various noise-makers, smoke, and "habitat improvement" on nearby Kure Island, designed to attract the Midway albatross population to Kure. These had little or no effect. Leveling the small dunes near the runway and asphalting the ground, to eliminate the updrafts of air on which the birds soar and to make the ground unattractive for the birds, was also initiated. These measures were remarkably successful, in terms of reduced number of birds soaring over the runway and in terms of reduced number of collisions with planes. If and when this operation is completed, it may eliminate the collisions without eliminating the birds. The other measures do not seem to be promising. We hope that the suggestion of planting Casuarina on Laysan and other nearby atolls "to make them more attractive to the albatrosses" will not be carried out.

In the summer of 1961 Dr. Harvey I. Fisher studied the Midway albatrosses, both from the standpoint of population dynamics and that of experimenting with possible "imprinting" of young birds by moving them to a new location, to see if they tend to return to the new location for breeding when they reach maturity.

One of the disturbing things reported by Mr. Chandler Robbins, Fish and Wildlife Service biologist who has been handling the Midway investigation, is a general irritation among the personnel stationed at Midway with the noises made by birds of various sorts and especially with the burrowing habits of the shearwaters. This has resulted in a certain amount of killing and harassment of the birds. There may be some connection between this and the reported recent reduction of the Midway albatross population, attributed to accident and vandalism. It appears, as also demonstrated by the negative correlation between people and seabirds in the Marshall Islands, that sea birds and people do not very successfully occupy the same habitats.

Mr. Robbins has prepared a report on the success of leveling experiments and on the current situation involving these birds which will soon be issued in the Fish and Wildlife Service Special Scientific Reports; nos. 38, January 1958, and 44, July 1959 includes earlier information.

Wake Island:

In September 1961 after the Tenth Pacific Science Congress, Dr. Bruce Halstead, director of the World Life Research Institute, conducted a scientific party to Wake Island to collect poisonous fish, in continuation of his previous studies of the "ciguatera" poisoning problem. Participants were Dr. and Mrs. Halstead, Drs. Donald Hessel and Richard Beltz, chemists, Messrs. Don Ollis and Robert Rutherford, photographers

and Miss M.-H. Sachet. The latter concentrated on the land ecology of the atoll, continuing observations made by F. R. Fosberg in 1951, 1952 and 1953 (see ARB no. 67, 1959). Insects and some reef animals, soil samples and especially herbarium specimens of land plants were collected.

Jaluit Atoll:

A follow-up study of the recovery of Jaluit from the effects of Typhoon Ophelia, January 1958 (see ARB 75) was undertaken in October 1960, by a party composed of Dr. David I. Blumenstock, Charles G. Johnson, Harold Rehder, and F. R. Fosberg, again under the auspices of the office of Naval Research and the Pacific Science Board. Marked changes were noted in some aspects, though the results of the typhoon are still very obvious in others. Coconut replanting has been completed and the economy of the people is well on its way back to normal. A preliminary note has been published summarizing the results of this visit (Nature 189(4765): 618-620, 1961) and it is hoped that a more extensive report can be completed soon.

Rongelap Atoll, Marshall Island:

As noted in Atoll Res. Bull. 70. p. 3, the University of Washington Radiation Biology Laboratory has extended its studies of fallout-contaminated areas in the northern Marshall Islands to some of the terrestrial aspects of the problem. Repeated expeditions under the direction of Dr. Edward E. Held have visited Rongelap Atoll and information on radioactivity levels in soils, land animals, and land plants has been collected. A detailed study of the soils of the atoll has been undertaken, and some experimental work to detect possible effects of low level radioactivity on plants has been done. Conversation with members of several of the expeditions indicates that the morbid appearance of many of the plants in the vegetation of the northern islets of Rongelap, observed in 1956 and reported in Atoll Res. Bull. 61, 1959, has persisted. This has been the object of some attention by the group, but as yet no convincing explanation has been advanced.

A paper by R. F. Palumbo and F. G. Lowman on the occurrence of antimony-125, Europium-155, Iron-55 and other radionuclides in Rongelap Atoll soil, has been issued as Report no. UWFL-56, by the Technical Information Service Extension, Oak Ridge, Tenn. At the IXth International Botanical Congress, Montreal, August 1959, R. B. Walker and E. E. Held presented a paper on radiocaesium in plants grown on Rongelap Atoll soils. R. F. Palumbo presented one at the same occasion on the differences in uptake of radioisotopes by marine and terrestrial organisms. Held has since published an abstract on Observations on two land crabs in the Marshall Islands (Bull. Ecol. Soc. Amer. 41: 51-52, 1960), presented at the meeting of the Ecological Society of America, Western Section, Eugene, Ore., June 14, 1960. It may be noted that the "crabs" referred to are the coconut crab and a hermit crab, rather than land crabs. S. P. Gessel, E. E. Held and R. B. Walker presented a paper on nitrogen studies of Rongelap atoll soils at the Tenth Pacific Science Congress. Other results should not be long in coming.

The notes on the condition of the vegetation on the northern islets of Rongelap by Dr. Baruch Blumberg, mentioned in ARB 70, p. 3, have been published by Blumberg and Conard as an addendum to a report by Conard, et al., on a Medical survey of Rongelap people five and six years after exposure to fallout, BNL 609 (T-179), pp. 85-86, 1960. Since this paper was published in a very obscure place, not likely to be seen by any student of atoll vegetation, it is reproduced below,* minus the map and photo.

These observations and those mentioned above by the radiation Biology Laboratory scientists make it obvious that the abnormal condition of the vegetation of the northern Rongelap islets is not merely a temporary phenomenon induced by climatic vicissitudes or accidental wave wash, and that the cause is not known. While we do not insist that there is any connection with the Castle fallout, as suggested in ARB 61, no better explanation seems to have been offered, at least none that is satisfactory to those familiar with the normal character and behavior of atoll vegetation. We have not seen any detailed outline of the plans and procedures of the present ecological study by the Radiation Biology Laboratory group, but there seems to be no indication that several of the possible lines of approach previously suggested to the U. S. Navy Radiological Defense Laboratory and by them to the AEC have been tried. Although so much time has elapsed that much of the evidence may have been lost, it still would seem appropriate to study in detail the condition of individual plants of the most affected species, of all ages from newly germinated seedlings to old and obviously injured plants, to excavate root systems and find whether the poor condition of the shoots is matched by corresponding pathology of the roots, to determine, histologically, the nature of the injury and the tissues affected, and to see if there is any unusual concentration of radioactive substances in these or any other tissues in the injured plants. There seems little point in devoting any more attention to Scaevola and Tournefortia (Messerschmidia), since both the Fosberg and Blumberg reports note that these plants completely failed to show the pathological conditions observed in other species. Finally, a detailed survey of the present condition of all species of plants on the different islets of Rongelap, by someone who is thoroughly familiar with their normal appearance under similar climatic conditions, should obviously be made and published so that an unbiased assessment of the situation could be made by anyone interested. It may be added that the pages of this Bulletin are open for preliminary publication of any available data on this problem and that such publication might serve an immediate purpose in stimulating new ideas.

*A note on the vegetation of the

northern islets of Rongelap Atoll, Marshall Islands, March 1959

B. S. Blumberg and R. A. Conard

"Fosberg[1,2] reported changes in the vegetation of the northern islets of Rongelap Atoll (observed in 1956) which he inferred might have been associated with the radioactive fallout that occurred on this atoll in 1954. During the medical survey of the Rongelap people[3] carried out in March 1959, an opportunity arose to visit some of these islets and to

re-examine the vegetation. A helicopter was available for transportation, which permitted general and detailed air examination as well as two short ground surveys. The northern islets were estimated to have received a radiation dose of $\approx$ 3000 r. The islets of Naen and Gegen were examined in greatest detail. The most striking feature observed from the air was the generally gray color of much of the vegetation, in contrast to its normal green color. Ground surveys revealed that *Scaevola sericea* was common and normal in appearance. Many of the *Guettarda speciosa* appeared to be in poor condition (Figure A-2). In some, all or nearly all the leaves were gone from the terminal 1 to 12 in. of the branches, and other leaves were yellowed and shriveled. In other *Guettarda*, nearly all the leaves were gone, and the bushes appeared completely dead. More than 50% of the *Guettarda* were affected in whole or part. In one area of Naen several hundred yards inland from the ocean beach, there was a field of $\approx$ 30 *Guettarda*, all of which were dead. Some young *Pisonia grandis* were seen which appeared to be in good condition. Mature *Pisonia* were seen which were partially defoliated, but these did not appear to be greatly different from those seen on Rongelap Islet on the southeast corner of Rongelap Atoll. None of the mistletoe-like clumps described by Fosberg were observed. Several *Ochrosia oppositifolia* were seen with nearly complete defoliation, which appeared dead. A small grove of coconut trees near the center of Naen Islet contained 4 to 5 dead trees within a radius of $\approx$ 300 yards, which were decapitated at heights 5 to 12 ft above the ground with no evidence of axe or machete marks. Two 2-headed coconut trees were seen, one with fronds that were mostly brown and appeared dead growing from the trunk $\approx$ 12 ft below the true crown of the tree. Several trees had dry and shriveled fronds, and $\approx$ 6 had deformed bulges 4 to 8 ft below the crown with apparently normal growth above the bulges.

"Photographs of the affected vegetation were examined by Dr. Fosberg, and he stated that the changes were similar to those he had previously reported.

"It is not possible to evaluate the cause of the changes from the present observations. More extensive and detailed botanical and ecological surveys will be necessary, both on the islands that received radiation and on those that did not, to determine whether the changes seen bear any relation to fallout. In particular, it should be noted that these observations were made during the dry season.

"We are indebted to Professor Frank Richardson of the University of Washington for identifying the plants, and to Commander W. Lyons, USN, for his assistance in taking the photographs.

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Caroline Atolls:

During the summer of 1960 Dr. Harvey A. Miller, of Miami University, Oxford, Ohio, led an expedition to collect material and to study certain aspects of cryptogamic botany and wood anatomy on the Caroline Islands. The active personnel on this trip were Dr. Miller, Henry O. Whittier, Less S. Dutton, Ernani G. Menez, and Alnus Oruetamor. The schooner Collegiate Rebel served as base of operations and transported the party between islands. Extensive collections of bryophytes and marine algae, and some wood samples with herbarium vouchers were prepared. The wood samples were shipped to the U. S. National Herbarium, the bryophytes to Miami University, and the algae to the University of Hawaii. In addition to the high islands a number of atolls were visited, including Mokil, Oroluk, Namonuito, Puluwat, Ifaluk, Sorol, and Pulu Anna. An outcome of this investigation is the undertaking, by Mr. Whittier, of the preparation of a bryoflora of the Micronesian atolls. In addition to the collections mentioned above, which were the principal objectives of the trip, Dr. Miller informs us that a collection of vascular plants was made on Mokil.

Ulithi Atoll:

On November 30, 1960, Ulithi was hit by Typhoon Ophelia (second of this name in Micronesia) and badly battered. In view of the interest of the Coral Atoll Program in the effects of typhoons on atolls, the Pacific Science Board and the Office of Naval Research sent a party made up of David I. Blumenstock, Charles G. Johnson, and William A. Lessa to Ulithi in January 1961, to survey the damage. Since Lessa had previously done ethnological work on Ulithi it was especially fortunate that he could be a member of the party. A summary of observations is being prepared for publication in Science, and it is hoped that a full report may be available for this Bulletin in the not too distant future.

Laccadive Islands and Minicoy:

Information has been received, through the Unesco Humid Tropics Programme, that the Botanical Survey of India, Western Circle, has carried out a collecting mission to the Laccadive and Minicoy atolls. No further details are available except that the herbarium specimens received have been incorporated into the Western Circle Herbarium, at Poona.

Alacran Reef:

Although the Pacific Science Board's Coral Atoll Program has functioned mostly in the Pacific, its scope extends throughout the tropical areas where coral atolls and similar islands exist. Therefore it is with great interest that we call attention to rather extensive studies of Alacran Reef, north of Progreso, Yucatan. The vegetation of this atoll was described in some detail by C. F. Millspaugh following a visit in 1899.

From 1955 to 1961, a number of expeditions from various institutions have visited and worked on Alacran, making it, by now, one of the better known atolls. Most of this work is as yet unpublished but several manuscripts are in press, including one by F. Bonet and J. Rzedowski on the

vegetation and one by L. Huerta Musquiz on the marine flora which have been submitted for publication by the Escuela Nacional de Ciencias Biologicas in Mexico City. Louis Kornicker and colleagues have published an excellent map of Alacran Reef and a general descriptive paper, including preliminary lists of animals found there (Inst. Marine Sci. Pub. 6: 1-22, 1959).

Work carried out during the summers of 1959 and 1960 may be indicated by quoting as follows from a letter, dated March 28, 1961, from Dr. J. T. Conover, chief scientist of the Duke University party:

"A bio-geological survey of Alacran Reef, Yucatan, was undertaken by the University of Texas and Duke University as cooperating institutions each supported by separate National Science Foundation grants (U. of T., NSF-G 8902; Duke U., NSF-G-12333). An account of the objectives and work of the University of Texas group in 1959 is given in a paper by Kornicker, Bonet, Cann and Hoskin in Vol. 6,1959, Publ. Inst. Mar. Sci. The objectives of Kornicker's group were to study the biogeologic genesis of a living reef and later to compare the results with fossil reefs and paleoecological considerations.

"The first summer (1959) Kornicker's group devoted their time to a general survey of Alacran atoll with emphasis on the geological features, the atoll profile and the general nature of the living communities. The second summer (1960) Kornicker and Boyd concentrated their attention on microatoll growth and sedimentary features related to the living communities around the sand cays. Charles Hoskin studied the distribution of grain size and mineral forms of calcium carbonate in the various facies of the entire atoll. Robert Folk and an assistant examined the sedimentation features of the sand cays with special consideration of the clastics and their distribution and orientation.

"The botanists, Conover and Perkins, measured the standing crop of the principle living plant communities by species population throughout the atoll along 10 transects. These data revealed the existence of a number of distinct community zones which reflect the growth character of the atoll. Results from this study provided an estimate of the living standing crop of benthic plants (not including the Zooxanthella in the polyp colonies), both non-calcareous and calcareous, with and without the lime incrustation by weight, in gms/m^2/ species. It was discovered that the windward slope of the atoll was firmly cemented by an extensive mantle of encrusting coralline algae. There was no lithothamnion ridge community, but in its place a sparsely populated, unconsolidated subtidal platform composed of loose blocks, boulders, cobbles and smaller fractions of coral and algal rubble. Even in the lagoon no deep deposits of sand were observed since all types of bottom were subtended by coarse fragments of coral-algal rubble (unconsolidated), no matter where the botanists drove in their coring tubes in the shoal waters. The nature of the deep channel bottoms may differ from these findings for shoal water facies. Also the features in the lagoons, reported in 1959 as patch reefs, were recognized as true faros, or microatolls, with similar growth features to the atoll's own characteristics. Benthic plant production is very high on the atoll, and contributes a large fraction of the calcium carbonate composing the

reef. An honest estimate of the amount of lime contributed by plants and animals in the living communities is one of the objectives of this study. Charles Hoskin is providing data on the subfossil and fossil estimates based on sediment analysis. Dr. Bonet intends to obtain a deep core from Alacran in the near future to provide additional data.

"Incidental to the major objectives, the nature of growth of micro-atolls or faros was investigated by the botanists. High temperatures and widely fluctuating salinities in the microlagoons of the faros suggested one possible reason for the scant life in these shallow sand-filled basins. The natural growth and death cycle related to age of the communities has been suggested as another reason. The exhaustion of nutrients in these small systems is another. Further studies on microatoll growth characteristics will be undertaken in the summer of 1961. It is believed that a shallow, faro-choked lagoon such as that at Alacran and in the Maldives atolls, may be related to the possible high transport rate by wind driven currents. These provide high nutrient levels, oxygenation, and perhaps warmth in winter (air temperatures go to freezing some days during the passage of a "norther" over Alacran) and cooling in summer provided by the exchange, as well as furnish spores and polyp larvae for seeding.

"Collections were made by Perkins of 5 representatives of the Phaeophyta at daily intervals over a month to study the lunar periodicity of their reproductive cycles on Alacran.

"Over 430 field numbers of benthic plants, a number of plankton tows, (which were surprisingly rich) and dredged samples from the bank in 35 fathoms of water were obtained during the five week survey.

"Data were obtained at each station (quadrat) including salinity, temperature, light (in ft candles), turbidity, depth and notes on the sedimentation features."

Participants were as follows:

Geologists: William Behrens, Fernando Bonet, Donald Boyd, Glen Cosh, Augustus Cotera, Robert L. Folk, Miles Hayes, Charles Hoskin, Edward Klovan, Louis S. Kornicker, Walter Pusey, Thomas Wright, and Amado Yanez; Botanists: John T. Conover, Laura Huerta M., and William Dana Perkins. Institutions represented were the University of Mexico, Instituto de Geologia, Mexico, University of Texas, University of Wyoming, Columbia University, Instituto Polytecnico, Mexico, Rice Institute, Rutgers University, and the University of Rhode Island.

Dr. Brian Logan, of Texas A. & M., visited Alacran, as well as the other cays on the Campeche Shelf, in February, 1960, in the course of his work on the Pleistocene history of the Campeche Shelf.

The summer of 1961 saw a continuation of work on Alacran, with several parties in the field. Dr. Bonet, with his assistant, Sr. Yanez, and a party of drillers, drilled a hole through several hundred feet of sediments on Perez Islet. Dr. Charles Hoskin, with Prof. Don Winston and Harold Illich made sedimentation studies and collected marine animals. Dr. John T. Conover, Prof. Harold Humm, Bruce Welch, and K. M. S.

Aziz studied algae and marine ecology. F. R. Fosberg made a brief survey of terrestrial ecological features and vegetation, as well as a collection of plants, with the object of comparing Alacran with Pacific atolls. Of special interest was the opportunity to compare present vegetation with that recorded in 1899 by Millspaugh. Change has been extreme.

The Atolls off British Handuras:

Until last summer among the least known atolls in the world were Turneffe, Lighthouse, and Glover's reefs, off the coast of British Honduras. In 1960 and again in 1961 these were visited by David Stoddart, of the Geography Department, Cambridge University. Detailed maps were made of many of the cays as well as collections of the plants growing on them. The processes of physiographic change were studied. A general report, mentioning briefly this work, as well as a popular book (see Recent Literature below), was issued on the 1959-60 Cambridge University Expedition. Detailed reports are expected. Meanwhile, Hurricane Hattie has swept these atolls. It is hoped that Mr. Stoddart will be able to return and compare the present physiography with his detailed maps, and further elucidate the role of hurricanes in shapping the cays.

Recent Literature

Two new journals of interest to the Coral Atoll Program have recently been launched. One of these is a quarterly called Pacific Insects, published by the Bishop Museum and edited by J. Linsley Gressitt. It includes systematic papers on insects of the Pacific Basin, some of which undoubtedly will treat atoll forms. None of the papers in the first number (1959) seem to record any atoll species. We have not seen the later numbers, though at least two volumes have appeared to date. An adjunct series to Pacific Insects, Pacific Insects Monographs, "devoted to monographs and other works too large for the journal", will be issued irregularly. Two numbers have appeared, the second of which (1961) is a review paper by Dr. Gressitt on Problems in the Zoogeography of Pacific and Antarctic Insects. This has a direct bearing on the insects of the Pacific coral atolls and an appendix by Miss Setsuko Nakata contains a record of a phasmid from Ebon Atoll.

Of the series, Insects of Micronesia, published under the same auspices, and containing many records of atoll insects, some parts of volumes, including two introductory volumes and 38 systematic treatments, have appeared to date.

The second journal is Cahiers du Pacifique, published at the Muséum National d'Histoire Naturelle, Paris, to contain material in all scientific and cultural fields touching the Pacific and lands bordering it. The Cahiers appear at irregular intervals, and of the three numbers published so far all contain articles of interest to students of coral atolls. The first number (Dec. 1958) has a paper on coral islands in the Tuamotus by Gilbert Ranson and a bibliography relative to coral in the Pacific for 1957-1958. In the second (June 1960) is a detailed history

of Clipperton Island, by M.-H. Sachet, including a comprehensive bibliography of works relating to or mentioning this easternmost atoll in the Pacific. In the third number (June 1961) are a summary of modern oceanographic researches in the South Pacific by Michel Legand and an article on the Great Barrier Reef and the Capricorn Group by P.-H. Fischer. In the latter are a map and description of Heron Island. In addition to original papers and review articles, each issue contains reviews of recent publications, news of the Pacific, and bibliographies on special subjects.

Next to the Great Barrier Reef of Australia, the reef complex of New Caledonia is perhaps the most important in the world, and it had so far remained rather poorly known. It is a pleasure to report that an extensive program of study of this reef has now been initiated by the French and is actively being pursued. Details are given in no. 3 of Cahiers du Pacifique.

We wish again to call attention to The Elepaio, Journal of the Hawaiian Audubon Society, and to emphasize that this little publication is becoming a major place of publication for information on atoll ecology, especially that of the Hawaiian atolls. In recent numbers E. P. Wilson describes the situation on Midway, which he visited in company with Chandler Robbins who was checking on results of the Navy's efforts to reduce the gooney bird hazard to aircraft; W. R. Smythe writes about monk seals on Laysan; Charles Hanson reports observations on Midway, with especial reference to the trouble between the Navy and the albatrosses; Richard Warner discusses Midway and Laysan in an article on the present status of the avifauna of the Hawaiian Islands; and Hubert and Mable Frings contribute a long article entitled Problems of Albatrosses and Men on Midway Islands. Here, in non-technical language, is a substantial amount of information on atoll ecology, and especially on the distressing situation on Midway discussed above.

Natural history of Ifaluk Atoll: Physical environment, by Joshua I. Tracey, Donald P. Abbott, and Ted Arnow, B. P. Bishop Museum Bull. 222: 1-75, 1961. This, the first of the series of reports of the Pacific Science Board Ifaluk Expedition, in 1953, is a fine piece of work. It includes a short description of the atoll, with photographs, followed by chapters on the physical environment and on the geology and hydrology. Under physical environment, climate and tides are discussed--thus this chapter heading refers to the environment of, rather than on, the atoll. Under geology and hydrology are sections on the geology of the islands, hydrology, reefs and lagoons, and a summary of geologic history. All of these subjects are treated in substantial detail, and well illustrated by photos, diagrams and maps. Separate large geological and sedimentary maps, and cross sections are provided. The detailed logs of the wells dug for an investigation of the hydrology provide much information on the soils which are briefly discussed. Very considerable attention is paid to the nature and material of the sediments, with descriptions and histograms showing the size, distribution and biological origin of the major constituents. No chemical analyses are reported. Earlier stands of the sea and changes in the outline, area and position of the islets are discussed at length. In most respects the information presented will provide an admirable basis for comparison with similar data from other atolls. This volume will certainly serve for a long time as a model, and for an indication of what can be accomplished in a relatively short visit to an atoll.

Dr. T. Goreau has written a short paper (Endeavour 20: 32-39, 1961) summarizing current knowledge and describing his own work on the mechanisms of calcium deposition and the role of zooxanthellae or endozooic algae in reef corals. The work was done on Jamaica reefs rather than on atoll reefs, but is of extreme importance in understanding reef ecology. It also includes a short bibliography of pertinent papers of a more technical nature.

In a paper on The role of algae in the formation of beach rock in certain islands of the Caribbean, Robert W. Krauss and Raymond A. Galloway conclude that algae play no direct role in the formation of this interesting rock, so characteristic of coral islands. They do not exclude the possibility of an indirect influence of algae in the process by means of their influence on carbon dioxide content of the water, or acidity. The paper appeared as Caribbean Beach Studies, Technical Report No. 11, Part E, from the Coastal Studies Institute, Louisiana State University, 49 pp., March 20, 1960. The distribution of these reports is unfortunately limited.

A major contribution to coral reef ecology has recently appeared, which stems in part from work initiated under the Pacific Science Board Coral Atoll Program, a paper by Robert W. Hiatt and Donald Strasburg on Ecological relationships of the fish fauna on coral reefs of the Marshall Islands (Ecol. Monogr. 30: 65-127, 1960). This brings together observations on the behavior, feeding habits, and stomach examinations of 233 species of reef-inhabiting fish collected on the Bikini Resurvey, the Arno expedition, and at the Eniwetok Laboratory, 2,051 fishes in all, 1185 of them collected at Arno Atoll. In addition the observations of Randall on the Onotoa Expedition are extensively cited. After placing this enormous amount of data on record in systematic order, the authors arrange the fish and discuss them according to habitat groups, then list them according to trophic levels, and finally, diagram and briefly describe the food web in the Marshall Islands reef ecosystem. Thus, not only is there presented here an impressive quantity of the raw materials of coral reef ecology, but the work constitutes an important step in the generalization of such information.

From Dr. George Scheer we have received three papers, two of them reporting results of the Xarifa expeditions, concerning the developmental history of stony corals, the other on the history of coral research, with a considerable bibliography. One of the papers is in Die Naturwissenschaften 10: 238-239, 1960, the others in Bericht 1958/59 Naturwiss. Verein Darmstadt 37-67, 1959.

Early attempts of Mormon missionaries to establish their church in southeast Polynesia, including the Tuamotus are described by Professor S. G. Ellsworth in a booklet entitled Zion in Paradise (1-35, Logan, Utah, 1959). Dr. Ellsworth, Associate Professor of history at Utah State University, is carrying on studies of the diaries of early Mormon missionaries in the Pacific, and we expect that this is only the first of many additions to literature on the atolls visited by these hardy people.

A brochure entitled Coastal Geography (anonymous, unnumbered, 17 pp., National Academy of Sciences--National Research Council, 1961) embodies the report of a Conference on Coastal Geography, held by an ad hoc

panel under the auspices of the NAS-NRC Committee on Geography, March 20-21, 1961. A very interesting program of research on coastal problems was proposed, but work on coral atolls was not mentioned; yet, because of the geographical nature of atolls, all problems involving them would seem to be coastal.

Harry Ladd has brilliantly summarized, for the non-specialist, current ideas and research on the geology and marine ecology of reefs and atolls in a well illustrated article entitled Reef Building (Science 134: 703-715, 1961). Results of the Eniwetok drilling are emphasized, with a cross sectional diagram, and a proposal for deep drilling on Midway Island is described, with a discussion of its significance. Mention should also be made of a paper by Ladd on the Origin of the Pacific Island Molluscan Fauna (Am. Jour. Sci. 258-A: 137-150, 1960), which has profound implications for the paleogeography and biogeography of the Pacific. His main thesis in this paper is that the Indo-Pacific marine fauna, instead of having originated in the Indonesian region and migrated into the Pacific may have originated in the Pacific and migrated into the Indonesian area.

Very worthy products of atoll investigations are popular books, that give the non-scientific public some insight into the hardships and hard work of expeditions, as well as the fascinations and satisfactions thereof. We saw this in Bates and Abbott's Coral Island. Now we have just received "From the Cam to the Cays", by David Carr and John Thorpe, an account of the Cambridge University Expedition to British Honduras, 1959-60, published by Putnam, London, 1961. This is a well written, well illustrated, and interesting account which makes good reading, and includes a chapter on Turneffe and Lighthouse atolls, which are little enough known and seldom visited by scientists. This chapter was written by our friend and correspondent David Stoddart, geographer from Cambridge University.

The greatest of all coral reefs, or rather, complexes of coral reefs, is the Great Barrier Reef of Australia, lining the Queensland Coast from Torres Strait to the Tropic of Capricorn. It has excited and intrigued the imagination of those interested in the sea and its beauties and mysteries since Captain Cook discovered it, became trapped in its maze of channels, and almost lost the tiny but famous Endeavour, in which he made his first voyage around the world. Many books have been written about this great reef, as well as innumerable scientific papers. The Great Barrier Reef Committee was organized by the Royal Geographical Society of Australasia to promote scientific investigations of it. The area includes about 200 flat coral islands or cays, some of which, such as Low Isles, have been carefully studied. The cays have much in common with the islets of oceanic atolls and their study sheds light on many ecological problems of atolls. On one of them, Heron Island, the Great Barrier Reef Committee maintains a laboratory, while on another, Green Island, there is an underwater observatory, providing excellent facilities for continuing study.

A magnificent introduction to this great ecological phenomenon has now been provided by Keith Gillett and Frank McNeill in, The Great Barrier Reef and Adjacent Isles, published by the Coral Press, Paddington, Sydney, Australia in 1959. This book of almost 200 pages describes the reef and

its islands in popular but accurate language, and is illustrated with magnificent photos. The main part, however, is devoted to descriptions and illustrations, many of them beautiful colored plates, of the animals likely to be found by visitors. After a visit to Heron Island, guided by this book, we can testify to its usefulness and readability.

We also welcome the appearance of Prof. Obermüller's beautifully illustrated work on the geology and mineralogy of Clipperton Island as one of two papers in a special volume entitled "Recherche géologique et minérale en Polynésie Française", Paris, 1959, published by L'Inspection Generale des Mines et de la Geologie. The other work in the same volume, by Professor Aubert de La Rüe, deals with the high islands of the Society, Marquesas, and Austral Groups with only brief mention of their surrounding reefs. It contains a liberal series of the author's magnificent photos, including a good one of beachrock.

Attention of atoll students is directed to a series of "library summaries" and "library brochures" on Pacific island and Pacific area geography, and other subjects of geographical interest in the Pacific, prepared for the Pacific Missile Range, Point Mugu, Calif., under the direction and editorial supervision of Dr. William L. Thomas, Jr., of the Geography Dept., University of California, Riverside, Calif. This series, of which we have seen 27 booklets, issued between July 1960, and January 1961, is difficult to refer to, as the booklets are not numbered, no publisher is indicated, and no mention is made of where or whether they are available or to whom. They do not bear any indication of security classification, however.

Each booklet contains a summary of available published information, with liberal quotations from sources which are listed in a bibliography. The work seems to be competently done, under the authorship of one or more compilers for each booklet, well organized, and clearly presented in offset reproduction, with maps and photos. In addition to a number of high islands, the following atolls are treated either by summaries or brochures: Taongi, (Pokak) Kapingamarangi, Cocos (Keeling), Majuro, Eniwetok, Johnston, Wake, Canton, and Midway. The only apparent difference between a summary and a brochure seems to be that the latter is regarded as more complete.

Matters of general interest

The outstanding recent scientific event in the Pacific area has been the Pacific Science Congress, held in Honolulu in August 1961. Although no programs were devoted specifically to coral atoll problems, many of the symposia and contributed papers touched on or had an important bearing on these problems. Notable among these were symposia on Man's Place in the Island Ecosystem, Pacific Basin Biogeography, Modification of Biotic Balance of Island Faunas and Floras, Plants and the Migrations of Pacific Peoples, Land Tenure in the Pacific, and Pacific Island Terraces: Eustatic? The published papers of these symposia will appear in due course either in the proceedings of the Congress or in appropriate journals. Some abstracts are available in the volume entitled Abstracts of Symposium Papers, distributed at the beginning of the Congress.

In the annual report for 1959 of the Institut de Recherches pour les Huiles et Oleagineux (IRHO), p. 20, is an announcement of the establishment on Rangiroa Atoll of a coconut experiment station with a staff of a director and two professional scientists. A paper entitled The improvement of the coconut palm production on the atolls of the Tropical Pacific was presented by Y. Fremond of the IRHO, in the Tropical Crops Improvement symposium at the Tenth Pacific Science Congress, dealing with the work and plans of this station. We await with interest the results of these investigations on the culture of this important atoll crop.

We are informed that Dr. Herold Wiens' massive work of integration of knowledge on coral atolls, written during the last several years as a major step in the Pacific Science Board's Coral Atoll Program, will soon be published by Yale University Press. It should enable us to view the field and to determine what should be done next.

Bulletin readers may be interested to know that an International Society of Tropical Ecology has recently been organized, under the leadership of Indian ecologists, to promote research and training in tropical ecology and to improve communication among those interested in the subject in different parts of the world. An inaugural meeting was held in January 1960, at Bombay, India, on the occasion of the Indian Science Congress; reports of the meeting were published in the first number of the society's Bulletin. This Bulletin is published at irregular intervals and two numbers have appeared so far. Books and monographs also may be published later. Membership is open to all who are interested in tropical ecology; the society is to be represented by vice presidents and national committees in countries other than India. Correspondence should be addressed c/o Central Botanical Laboratory, 10 Chatham Lines, Allahabad, India. Fees and dues are: admission $2.00 U. S. or 0/15/0 Sterling; individual membership $5.00 or 1/15/0; institutional membership $7.00 or 2/10/0; life membership $70.00 or 25/0/0; applications and checks should be sent to the treasurer. In America correspondence may be addressed to and checks made out to F. R. Fosberg, senior vice president and U. S. representative (Pacific Vegetation Project, % National Research Council, Washington 25, D. C.). Those interested in coral atoll ecology are cordially invited to join.

Errata in Bull. 74, Birds of the Gilbert and Ellice Islands Colony by Peter Child

p. 3, par. 1, line 11: instead of "last-names" read "last named".

p. 4, line 2: instead of "Peter's" read "Peters'".

p. 4, last-but-one paragraph, line 2: instead of "of" read "or".

p. 4, last-but-one paragraph, line 2: instead of "bikeman" read "Bikeman".

p. 13, under 12 Sula sula: instead of "Keta" read "Kota".

p. 23, last paragraph, line 3: instead of "freedly offerred" read "freely offered".

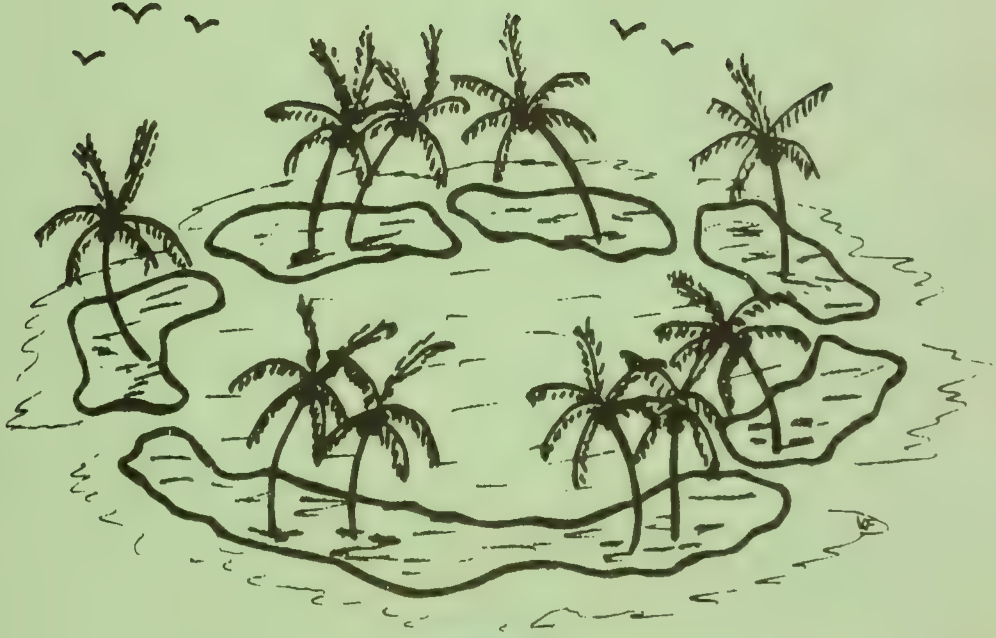
p. 31, line 4: instead of "thousand" read "thousands".

No. 85

December 31, 1961

ATOLL RESEARCH BULLETIN

85. Land tenure in the Pacific
A symposium of the Tenth Pacific Science Congress
convened by Edwin Doran, Jr.



Issued by
THE PACIFIC SCIENCE BOARD
National Academy of Sciences—National Research Council
Washington, D.C., U.S.A.

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LAND TENURE IN THE PACIFIC

A SYMPOSIUM OF THE TENTH PACIFIC SCIENCE CONGRESS

Convened by

Edwin Doran Jr.

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Washington, D. C.

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The sole responsibility of all statements made by authors of papers in the Atoll Research Bulletin rests with them, and they do not necessarily represent the views of the Pacific Science Board or of the editors of the Bulletin.

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Correspondence concerning the Atoll Research Bulletin should be addressed to the above

c/o Pacific Vegetation Project
National Research Council
2101 Constitution Avenue, N.W.
Washington 25, D. C., U. S. A.

PREFACE

The Symposium on Land Tenure in the Pacific formed a portion of the program of the Tenth-Pacific Science Congress which met in Honolulu, Hawaii from August 21st to September 6th, 1961. The papers which follow are a verbatim transcript of those presented in this symposium on the morning of September 1st.

Persons taking part in the symposium are as listed:

Convener:

Edwin Doran Jr., Associate Professor of Geography
A. & M. College of Texas, College Station, Texas

Authors of papers:

Richard Turpin, Registrar of Cooperative Societies
Betio, Tarawa, Gilbert and Ellice Islands Colony
(paper presented in abstract only)

Maynard Neas, District Administrator
Ponape District, Trust Territory of the Pacific Islands

M. M. Townsend, District Commissioner
Malaita District, Auki, Malaita, B.S.I.P.

R. H. Regnault, Deputy Director
Lands and Survey Department, Suva, Fiji Islands

Q. F. Pilling, Assistant Secretary
Office of the Premier, Nuku'alofa, Tonga Islands

R. G. Cromcombe, Research Fellow
Research School of Pacific Studies, Australian National University, Canberra, A.C.T., Australia

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JAVA SEA
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Bawean
Tg. Selatan
Madoera
JAVA
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Soemba
Soembawa
Flores
Timor
SAWOE SEA
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INTRODUCTION

Edwin Doran Jr.

Purpose and Organization

The objectives of this symposium are not so grandiose as the brief title might imply. A meeting of size perhaps comparable to the Tenth Congress would be required to treat in detail with the vast scope of land tenure problems viewed in time and space for the entire Pacific Oceanarea (Fig. 1). Our much more limited purposes are twofold, to examine a few current problems of land ownership in several well-dispersed island groups and to illustrate the utility of a slightly different cross-disciplinary approach to such problems than those of former Congresses.

The significance of problems of land tenure everywhere need not be emphasized to this audience. The intimate connections of man with the earth which provides his needs and the ever-increasing numbers of humans competing in a finite area which decreases in quality as they misuse it - it is indeed ironic that these are the commonplaces of today.

Since land tenure problems are of magnitude and are ubiquitous it was felt that comparative studies from several parts of the Pacific might be useful. Westernized areas such as Hawaii, New Zealand, and Australia were excluded from comsideration, and an attempt made to obtain contributions from the Gilbert and Marshall Islands in Micronesia, from the Solomon and Fiji Islands in Melanesia, and from the Cook Islands in Polynesia.

It is recognized commonly that problems of land tenure are cross-disciplinary in nature, and that no one person can have a background

NORTH PACIFIC OCEAN
UNITED STATES
HAWAIIAN ISLANDS
PHILIPPINE SEA
SOUTH CHINA SEA
EAST CHINA SEA
YELLOW SEA
CHINA
KOREA
TAIWAN
PHILIPPINE ISLANDS
MARIANAS
CAROLINE ISLANDS
MARSHALL ISLANDS
BORNEO
NEW GUINEA
BISMARCK ARCHIPELAGO
SOLOMON ISLANDS
JAVA SEA
BANDA SEA
ARAFURA SEA
TIMOR SEA
CORAL SEA
AUSTRALIA
FIJI ISLANDS
SAMOA ISLANDS
TOKELAU IS
PHOENIX ISLANDS
ELLICE IS
GILBERT IS
MARQUESAS IS
SOCIETY ISLANDS
TUAMOTU ARCHIPELAGO
COOK ISLANDS
TUBUAI OR AUSTRAL ISLANDS
MEXICO
GULF OF MEXICO
BAJA CALIFORNIA
San Francisco
Los Angeles
San Diego
Kauai
Oahu
Hawaii
Johnston
Wake
Palmyra
Christmas
Clipperton
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Pitcairn
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completely adequate for their solution. The single individual who often is forced to act on problems, despite his awareness of shortcomings in available information, is the administrator. It was thought that it might be stimulating to present problems as seen through the eyes of those in most immediate contact with them, hence four papers this morning are presented by administrators.

In an area of relatively primitive people, whose cultures may be basically different from those of western civilization, it is imperative that the studies and advice of anthropologists be considered in attempting solutions to problems of land tenure. We are fortunate in having on the program a person who has studied such problems intensively in several Polynesian groups and can illuminate them from an anthropologic viewpoint.

Finally, the organization of this program and the introductory statements on each area may be taken as a possible illustration of the integrative facility and insight which geography can contribute to problems of land tenure.

Administrative Details[1/]

Certain administrative matters may be mentioned at this point. Several of the maps used as illustrations are taken from various United States or British governmental sources. Those illustrating relief and rainfall of Viti Levu are taken from Derrick's Geographical Handbook of the Fiji Islands. The photographs are mine except for aerials of Rarotonga and Tongareva taken by the U. S. Navy.

Unfortunately, only two of the six persons presenting articles are with us in person this morning. Due to travel problems Messrs.

1/ This section is appropriate to the verbal presentation only.

Pilling, Regnault, Townsend, and Turpin are unable to attend the meeting and their papers will be read by proxies whom I shall introduce at the appropriate time.

Finally, since it is intended that the symposium have a unitary character will you please reserve your questions until all the papers have been presented?

GILBERT ISLANDS LANDSCAPE

Edwin Doran Jr.

The sixteen atolls and islands which comprise the Gilbert Islands are strewn across the equator, not far west of the Date Line, for more than 400 miles from southeast to northwest (Fig. 2). An uneven distribution into such clusters as the Abemama-Kuria-Aranuka group, separated by 40 or 50 nautical miles of open ocean from adjacent atolls, has been of some importance historically and in the development of present land-holding patterns.

The islands are typical atolls, for the most part, with a central lagoon, elongated from southeast to northwest, and a surrounding chaplet of low-lying coral islands barely protruding from the sea (Fig.3). Individual islets are miles long but only furlongs-wide, and a few minutes' walk takes one from the ocean shore, where waves breaking on the fringing reef send up showers of spume, across to the quiet lagoon beach with its gently lapping wavelets. Variations in land surface along the long axis of islets are slight indeed. The most pronounced occur at breaks between islets where tidal channels connect ocean and lagoon or at lower land areas where storm washovers have reduced soil and vegetation to meager quality. By contrast, and in much shorter distance, the changes across widths of islands are marked and significant, in terms of exposure to wind and salt spray, in vegetation, in launching sites for canoes, and many others. The natural environment suggests strongly to man that the advisable manner of dividing up his lands is in cross-island units, and this usually he has done.

In most respects the Gilberts are favored with a pleasant, tropical maritime climate. Temperatures are equable and almost never vary more than ten degrees from an annual mean of about 82 degrees. The hottest

mid-day usually is moderated by strong breezes off the ocean, and winds of typhoon velocity are nearly unknown. By contrast the sparsity and variability of rainfall stand out with especial clarity. The westward extension of the dry equatorial tongue crosses the southern Gilberts, hence annual rainfall in this part of the chain is as low as 41 inches on Tabiteuea. Increases to over 50 inches at Arorae and to well over 100 inches at Butaritari occur transitionally to south and north. Even these figures, however, are insufficient to describe a variable climate in which annual rainfalls fluctuate markedly, as the recorded range from 15 inches to 115 inches at Tarawa examplifies. Since an annual rainfall of about 32 inches divides humid from semi-arid climates under these temperature conditions it is evident that the central Gilberts are not far removed from drought at best and that most of the chain is likely to suffer from time to time.

Under the edaphic and rainfall conditions which prevail vegetation inevitably must be sparse. Coconut trees are the dominant cover and thrive except in drier years, pandanus is hardy and a perennial food source, and babai, the coarse taro-like root, provides starch. An impoverished flora, with such species as Scaevola, Pemphis, and Rhizophora, fulfills most basic needs for fuel and construction materials, although formerly canoe building often had to await discovery of a properly large drift log.

According to recent estimates the population of the Gilbert Islands is approximately 33,000, equivalent to a population density of 288 persons per square mile. Since this is one of the greatest densities in the Pacific and occurs on islands sparse in rainfall and resources it is evident that problems of land tenure here are inevitably considerable.
How close this density approaches the maximum number that could be

supported under an economy of subsistence agriculture and fishing is, of course, a critical question to which no good answer can be given. Although a density of 520 per square mile has been suggested as feasible Maude questions such a concentration. Some insight is provided by the crude population estimate of 40,000 persons able to occupy the Gilberts at the time of the Wilkes Expedition of 1841.

Another approach, based on the idea that rainfall is a limiting factor on food production and hence on population is to compute a Kendall's rank correlation coefficient relating rainfall and population density of the several islands (Table 1). One might suspect that islands with heavier rainfall could support denser populations and that there should be a correlation between the two factors. The coefficient which emerges, 0.457, lies just within the limits of chance occurrence, and the suspected relationship is not firmly established. [1/] From this one could argue that populations as yet have not reached the maximum imposed by available rainfall but may well be approaching this limit.

1/ A correlation coeffieient larger than 0.475 would be significant at the .05 level.

TABLE 1

GILBERT ISLANDS: POPULATION DENSITY-RAINFALL RANK CORRELATION

Island (or atoll)	Popul.	Area	Density	Rank	Rainfall	Rank
Makin	1130	2.8	405	4	100	2
Butaritari	2118	4.5	470	2	122	1
Marakei	1790	3.9	460	3	71	4
Abaiang	3234	11.0	295	7	74	3
Tarawa	7125	7.7	925	Omitted	64	Omitted
Maiana	1359	10.4	130	13	57	5
Abemama	1341	6.6	205	11	53	6
Kuria	541	5.0	108	14	48	10
Aranuka	571	6.0	95	15	49	9
Nonouti	2143	9.8	215	10	43	13
Tabiteuea	3266	19.0	172	12	41	15
Beru	1968	8.1	245	9	45	12
Onotoa	1542	5.2	305	6	46	11
Nikunau	2011	7.0	290	8	42	14
Tamana	1142	2.0	515	1	50	8
Arorae	1551	5.0	310	5	52	7
Total	32832	114.0			957	
Average			288		60	
Cases				15		15

Rank Correlation Coefficient = 0.457


173°
174°
175°
176°
177°
3°
2°
1°
0°
1°
2°
Makin Meang
Butaritari
Marakei
Abaiang
Tarawa
Maiana
Abemama
Kuria
Aranuka
Nonouti
Tabiteuea
Beru
Nukunau
Onotoa
Tamana
Arorae
GILBERT ISLANDS


173°00'
173°10'
1°35'
1°30'
1°25'
1°20'
BETIO
BAIRIKI
TARAWA
173°00'
173°10'

LAND TENURE PROBLEMS, GILBERT AND ELLICE ISLANDS

Richard Turpin

(Due to communications difficulties only an abstract can be presented.)

Location, area, small scattered atolls over large area, diversity of rainfall and population density.

Before European contact land in Gilberts generally individually owned but restrictive customary rules governed disposal. On islands governed by High Chiefs land was vested in High Chief who distributed rights in lands.

In the Ellice Islands lands also vested in High Chiefs who disposed of rights to followers.

Land itself of little economic value until middle nineteenth century when coconut-oil first exported - nevertheless had social values - pits for babai and taro of greater food value.

After contact land had greater value as coconut-oil or copra exportable - islands fortunate that little land alienated.

Nevertheless increased value plus increasing population caused increased number disputes.

In early years Government, inadequate machinery for settlement disputes and registration but remedied after 1946.

Continuation of modified customary tenure causes fragmentation and subdivision of lands - no unused lands available.

Land hunger and surfeit exist on same islands - maldistribution.

Resistance to change stems from natural inertia plus fear of landlessness which could result in loss of security in old age or sickness and lack of alternative means of livelihood.

Security of tenure and machinery for settlement of disputes and for registration now exist.

Problems are maldistribution, fragmentation, sub-division.

Legislation now enacted enables neglected lands to be purchased for land hungry.

Customary tenure codes are not unchangeable and future more educated generations may wish to adopt less restricted form ownership.

Emigration has been tried on small scale and is possibility for future.

Variations of problems on some islands.

MARSHALL ISLANDS LANDSCAPE

Edwin Doran Jr.

The diagonal trend of the Gilberts is extended northwestward by the Marshall Islands (Fig. 4). At first sight, and in essence correctly enough, one would consider the two groups as conforming to much the same pattern. Each has a linear arrangement of tiny atolls sprinkled across vast ocean space, and Majuro Atoll appears rather similar to Tarawa (Fig. 5). In both groups islets of coral debris surround extensive lagoons, vegetation is relatively sparse although varying in profusion with the amount of rainfall, and small area combined with large ocean distances combine to form major difficulties for man's occupation.

A closer examination, however, reveals significant differences in physiognomy between the two groups of islands. If the total land area of inhabited islands (atolls) within each group is divided by the number of such islands it develops that the average Gilbert island(atoll) has an area of 7.1 square statute miles whereas the average Marshall island (atoll) has an area of only 2.65 square miles. On the average, then, each Gilbert island (atoll) is 2.7 times as large as each Marshall island (atoll). If the same procedure is used for the area of lagoons, however, precisely the opposite develops; the average Marshallese lagoon on an inhabited atoll is 181 square miles, the Gilbertese lagoon is 67 square miles, and the relation is again 2.7 but in favor of the Marshallese lagoon (Table 2). Curiously enough an approximately similar ratio obtains for lagoon depth; the average lagoon in the Marshalls is 137 feet deep or 2.4 times as deep as the 57-foot average for the Gilberts. Again the ratio

appears, but in opposite form, in reef width; the 4850-foot Gilbertese reef is on the average 3.2 times as wide as the 1500-foot Marshallese reef. Larger lagoons imply longer reefs, evidently, and the total reef area of the Marshalls is estimated at 312 square miles as compared to a total of 212 square miles in the Gilberts. Greater length more than compensates for lesser width (Table 3).

Turning now to population we note that somewhat more than twice as great a Gilbertese population, as compared to the Marshalls, is concentrated on somewhat less than twice as much land area, producing a density for the former of 288 persons per square mile, for the latter 235 per square mile. The greater population, however, is concentrated on fewer islands so that the average population per island is 2050 versus 620 or 3.3 times as large.

Let us now examine a few of the interrelationships significant to problems of land tenure which emerge from these statistics.

Since the average island (atoll) in the Gilberts is three times as large as in the Marshalls one can deduce, in the absence of accurate measurements, that in general the ground water supply must be better in the former. This follows from the known character of atoll freshwater lenses, which, in size and quality, are a function of individual islet size. The utility of vegetation and land and probably soils as well would appear to be greater in the Gilberts because the peripheral fringe of Scaevola and other salt-tolerant but relatively useless forms is an appreciably smaller proportion of the total vegetated area. And since the population per island (atoll) averages three times that in the Marshalls there would appear to be inherent economies of scale accruing to the Gilberts. Maintenance

TABLE 2

Island Group	Inhab. Area*	No. Inhab. Islands (atolls)	Ave. Area*	Ratio
Gilbert Is.	114.0	16	7.10	2.7:1
Marshall Is.	61.0	23	2.65	

Island Group	Lagoon Area*	Inhabited Atolls (s.str.)	Ave. Area*	Ratio
Gilbert Is.	738	11	67.0	1:2.7
Marshall Is.	3624	20	181.0	

* Area in square statute miles

TABLE 3

Island Group	Ave. Lagoon Depth, ft.*		Ave. Reef Width, ft.*		Total Reef Area, sq. mi.**
Gilbert Is.	57	1:2.4	4850	3.2:1	212
Marshall Is.	137		1500		312

Island Group	Population	Inhab. Islands (Atolls) Number	Inhab. Islands (Atolls) Area	Popul. per Island (atoll)	Popul. Density
Gilbert Is.	32,832	16	114.0	2050	288
Marshall Is.	14,290	23	61.0	620	235

* Data from Nugent, L. E. Jr. (1946) Coral Reefs in the Gilbert, Marshall, and Caroline Islands. Bull. Geol. Soc. Amer. 57:735-780. Nugent's data for individual atolls have been averaged.

** Data from Nugent, op.cit. Figures here are summations of his atoll reef lengths multiplied by average reef widths minus atoll land areas. The potential errors in such extrapolations are evident.

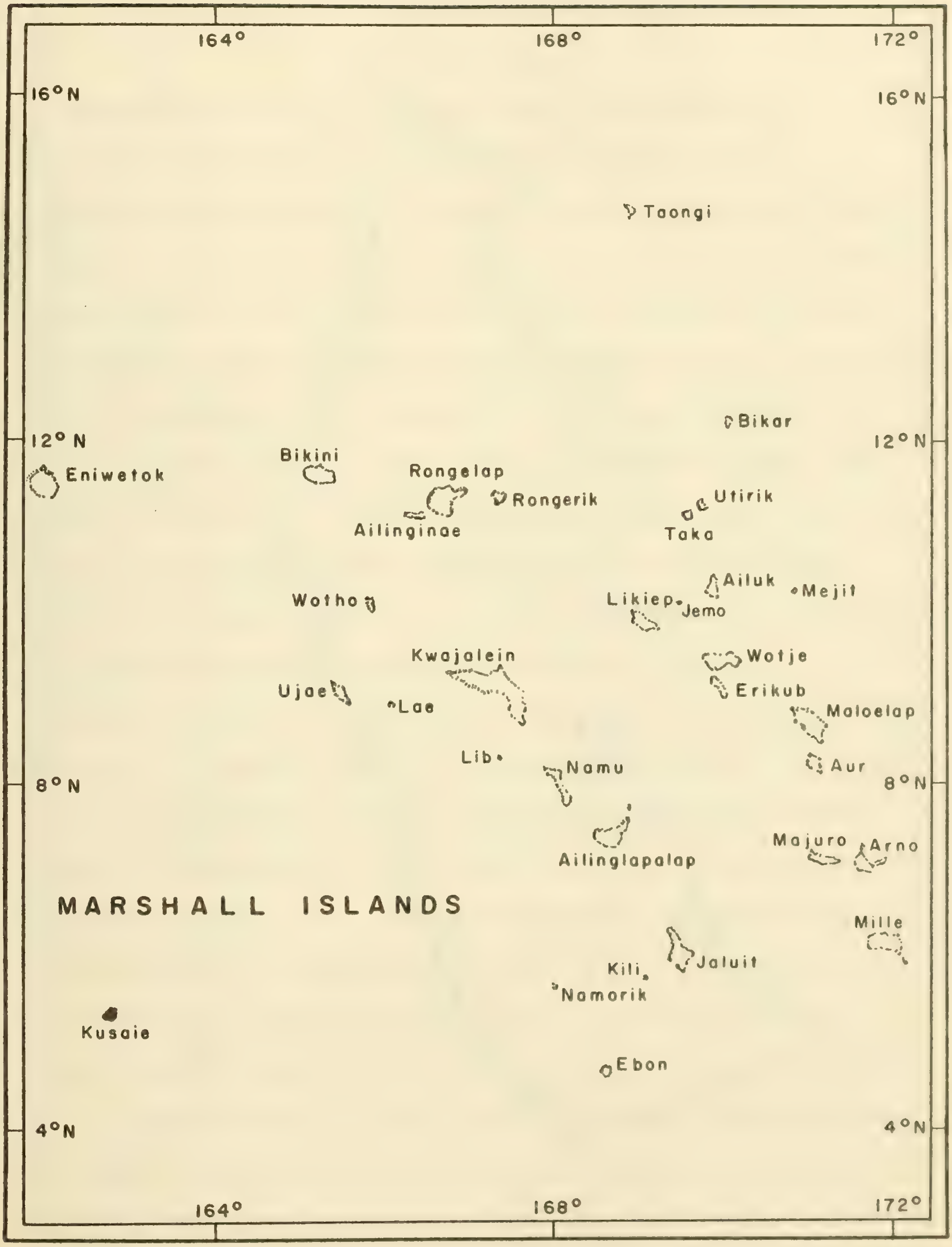
of schools, hospitals, and trading centers is more efficient with larger population, collection of the copra harvest for overseas shipment is facilitated, and control over land use should also be more easily accomplished.

In maritime affairs, however, the advantage is reversed. Most Marshallese atolls have large lagoons which are essentially reef-free and accessible from the ocean through deep passes, whereas the coral-choked lagoons and paucity of good harbors in the Gilberts are conspicuous disadvantages. Not only is this the situation today, but it must have been true also during indigenous times when large canoes had much the same requirements as modern trading schooners. The northwesterly orientation of the two groups also was of significance during the days of sailing canoes and still is where sails are used. The Marshalls, north of the equator and with northeasterly winds, are ideally oriented for sailing up or down an island chain, in either case with the wind on the beam in a position not requiring tacking. Good harbors and ease of communications along the two Marshallese chains may well have had much to do with their pre-European centralized chiefdoms. The Gilberts, with dominant southeasterly breezes, provided easy sailing toward the northwest but a wet and unpleasant beat back in the other direction. This may have had something to do with its lack of centralized control except in small contiguous groups. These environmental relations must not be overemphasized, but they certainly have some effect.

Catala's study in the Gilbert Islands has emphasized the importance of reef areas in evaluation of atoll resources. Formerly control over reefs was a chiefly prerogative; with the Western concept of

government ownership of land below the high water line such areas now form unsolved problems of land ownership and are little understood from the viewpoint of quantitative contribution to food supply. All would agree that food collected on the reef is significant in atoll diets; few would suggest that this source is more important than equivalent areas of land. If a unit area of reef provides one-tenth as much food as a similar area on land one might argue that the effective land area has been increased by one-tenth of the total reef area. If we apply this "reef utility factor," as it might be called, to the reef areas of both the Gilberts and Marshalls, multiplying the respective reef areas by it and adding the resultant useful area to the total land area, then population densities for the islands are reduced markedly. The Gilberts drop from 288 per square mile to 243, the Marshalls from 235 down to 156.

This is largely an exercise in speculation, but it emphasizes the necessity for obtaining accurate, quantitative data on the actual utility of reefs in order to properly evaluate atoll population densities. Proper allocation and conservation of reef resources evidently is a significant aspect of land tenure problems on atolls.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168°
172°
16° N
16° N
Taongi
Bikar
12° N
12° N
Bikini
Eniwetok
Rongelap
Rongerik
Utirik
Ailinginae
Taka
Ailuk
Mejit
Wotho
Likiep
Jemo
Kwajalein
Wotje
Ujae
Lae
Erikub
Maloelap
Lib
Namu
Aur
8° N
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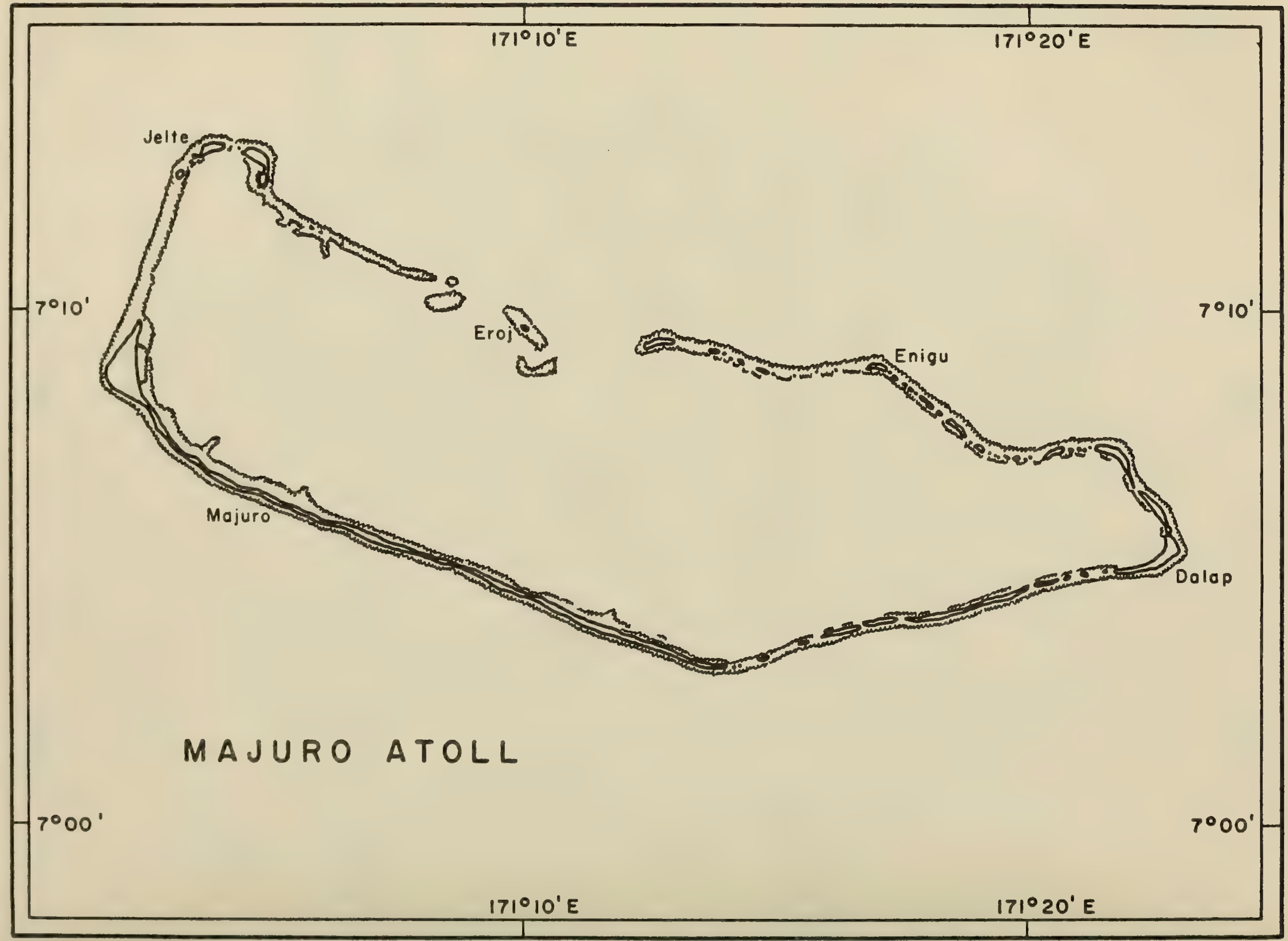
Ailinglapalap
Majuro
Arno
MARSHALL ISLANDS
Mille
Jaluit
Kili
Namorik
Kusaie
Ebon
4° N
4° N
164°
168°
172°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171°20'E
7°10'
7°10'
Jelte
Eroj
Enigu
Majuro
Dalap
MAJURO ATOLL
7°00'
7°00'
171°10'E
171°20'E

LAND OWNERSHIP PATTERNS IN THE MARSHALL ISLANDS

Maynard Neas

The Marshall Islands begin approximately 2,000 miles southwest of Hawaii. They consist of 29 atolls and 5 separate islands, inhabited by 15,000 Marshallese people, and constitute an administrative district of the United States Trust Territory of the Pacific Islands. Administration of the Marshalls is in accordance with a trusteeship agreement between the United States and the United Nations. These low coral formations, no point over 25 feet above high water, contain only 70 square miles of dry land. There is 700 miles of ocean between Narikrik Atoll in the southeast corner of the district and Ujelang Atoll in the northwest corner. The Marshalls are in the northeast trades of the Central Pacific between 4 and 15 degrees North Latitude and between 162 and 172 degrees East Longitude. Temperatures average 80 degrees F. Rainfall varies from 160 inches in the southern regions to less than 50 inches in the northern sections.

It is quite probable that Marshallese land tenure is very much today as it was 1,000 years ago. Their land tenure is based on a matrilineal society. All children inherit lands from their mothers. There cannot be any illegitimate children. There are no landless people and their land tenure pattern is the most important single factor of their lives. All children become members of their mother's clan. However, the clan is not a factor in the land ownership pattern. A paramount chief in the Marshalls is not a clan chief. His powers are associated with specific land parcels and the people that live on them.

A land parcel is controlled by a paramount chief, a family head and an undetermined number of commoners, or workers as they are sometimes

called. Each land parcel has a name and a history. The relative interests of various owners are seldom determined exactly. Formerly, powers of a paramount chief were absolute. The chiefly powers started to decline with the establishment of the German protectorate. Corresponding with the decline of chiefly powers, the commoners have gained in power and status.

Arguments over land provide the Marshallese with a form of entertainment and excitement in an area where a great premium is placed on anything that will break the dull monotony of isolated life. Land is so scarce it has acquired more than use values. The ocean and lagoons provide most of the food for the 15,000 Marshallese. Land is the foundation of prestige and social position. It is never bought or sold. It may become the subject of a gift, even to total outsiders, but its value is completely beyond the command of money. It is something to fight and die for.

Under the present Trusteeship civil war is prohibited and acquisition of land by foreigners is impossible. Land is something to acquire by intrigue, marriage, magic and sharp legal action in addition to acquisition by normal inheritance. There is no serious dispute in the district without foundation in a land dispute.

Marshallese land parcels are usually of three to four acres each. The tendency is to leave the parcels intact. Any number of commoners may hold rights in a given parcel but only one each of the higher levels may exist at any one time in the same parcel. The commoners work under general direction of the family head, who in turn answers to the chief.

There is only one cash crop - copra. Division of cash proceeds varies

from place to place from time to time. Duties and responsibilities on a particular land parcel will show the general picture. Copra was selling at $4\frac{1}{2}$¢ per pound. The paramount chief received $\frac{1}{2}$¢ per pound, the family head got $\frac{1}{2}$¢ and the worker kept the remainder, or $3\frac{1}{2}$¢. Generally, the chief's and family head's shares do not vary. As copra prices rise or fall, the worker gets more or less. The commoner must tend the land. He must keep underbrush down and maintain the land in condition to produce food and copra. The commoner must furnish his own knives and other simple tools. He must make and market the copra and remit shares to chief and family head. Any of the three levels may live on the land and take food from it but none has to maintain a residence on it. The commoner plants new trees and other food plants. Any major change in planting arrangement must be agreed to by family head and commoner. The commoner gives first fruits to the family head who in turn delivers these to the chief. The question of who is the chief for this parcel is in violent dispute. The family head personally recognizes a different chief than the one recognized by the workers and the High Court of the Trust Territory. This case was in dispute in the civil war that was raging in Majuro Atoll at the time the Germans stopped all local armed conflicts. It has been in dispute for over a hundred years and the wrangle may continue for another hundred. The commoner may use as many coconuts and other food products from the land as he needs for home use without any accounting. In case the worker doesn't do his work, the family head will step in and see that it is done and take the commoner's copra share. During the Japanese administration the division of copra proceeds was fixed by the Government. Now it is left to the people concerned.

Absolute chaos reigns today with respect to actual land ownership and relative interests of owners. They can determine three or four principal persons who hold rights on a given parcel with some certainty. But the number of people with some shade of interest in many parcels is indeterminable. Contact with 20th century civilization has brought many, many problems. For example, the Rongelap people were moved from their home atoll in March, 1954 after sustaining serious burns from nuclear fallout originating at a hydrogen bomb test at nearby Bikini. There were 82 pople on Rongelap at the time of the fallout. All were moved to Majuro Atoll where they remained for three years while their home atoll lost its deadly nuclear energy. New homes, at no cost to them, and free food helped approximately 200 additional people discover they were of the Rongelap land-holding lines and therefore eligible to share in the handouts of the United States Atomic Energy Commission.

In an area of dedicated travellers like the Marshallese, together with relatively loose sex customs, it is quite probable that reasonably strong proof could be brought to show any given Marshallese as having some degree of kinship to a substantial percentage of the entire population. When it is necessary to determine legal ownership of land, the Trust Territory Code requires the case to go before the High Court of the Territory. There is a special rule of the High Court pertaining to land cases in the Marshalls, together with four key decisions handed down by the Court during the past 10 years. The special rule requires the plaintiff to name the person he recognizes as his paramount chief on the land in question; what action the paramount chief has taken on the matter and what action the plaintiff

has taken to obtain a determination of his rights through traditional Marshallese channels. The substitution of open court for the arbitrary decisions of past German and Japanese administrations and the civil wars of pre-contact days, has brought considerable confusion. Why go to court if you don't get what you want? Any loser of a court case is apt to feel that he should be able to continue to present the matter to the court from time to time until he does get the case decided the right way. Obviously, his way.

The first key case established the principle that land matters officially and clearly decided by the German and Japanese administrations would be given full legal standing. Various levels of ownership were recognized. The Court ruled as follows:

"The present Marshallese system of land ownership is basically feudalistic. So far as we can determine, there is no helpful general analogy between the Marshallese system of land ownership and anything common in English-American history since the days of feudalism. All the different levels of owners have rights which the Courts will recognize, but they also have obligations to each other which severely limit their control over the land. There is duty of loyalty all the way up the line from commoner to head of family to little chief to paramount chief. A corresponding duty of protection of the welfare of subordinates running (sic) down the line and a strong obligation of cooperation running both ways. Thus, the rights involved are a combination of strictly private or property rights and rights or powers somewhat like those going with a public office."

The second key case contained the elements necessary for the Courts to establish limitations on the powers of paramount chiefs. Limine,

the plaintiff, was properly recognized and established as the family head of a lineage by his paramount chief. He committed some personal acts the chief did not like. However, his actions as family head were satisfactory to all concerned. No complaint was entered with respect to these actions. Nevertheless the defendant was named as family head by the paramount chief in place of Limine. The High Court ruled that there was no good reason for the change and re-established Limine as family head. The court found the paramount chief had acted in complete disregard to the rights which the chief himself had established. This the Court ruled "...is considered both unreasonable and contrary to the Marshallese customary law."

The third case involved the legal limitations of a will. The Court ruled as follows: "Under Marshallese customary law the approval of the paramount chief, or those entitled to exercise the paramount chief's powers, is necessary to make a will of rights effective and is one of the most important things about it." The paramount chief has power to determine whether, under all the circumstances, the necessary people have been consulted about a will or have consented to it. The Court ruled that the paramount chief may approve a will in part and disapprove another part. His decision, if properly made, will be binding no matter how clear it is the person making the will desired something entirely different.

The fourth case established the right of paramount chiefs to take away rights on lands under them when there is good cause. A family head, with the approval of his paramount chief, withdrew from his position as family head with respect to a certain land parcel. He named a daughter of his brother to succeed him as family head prior to

his death and to remain in the position after his demise. A certain lineage was given the commoner rights on the land parcel with the stipulation that the commoners would take care of the family head. This arrangement worked well for over 10 years. Eventually, neither side would cooperate or work together. The paramount chief took away all of the rights of both feuding sides in the given land parcel and gave them to other people. The Court ruled that this was entirely proper and legal. The various people holding the land rights reached the point where they were bickering and were not working the land properly. Therefore, the Court concluded, the paramount chief was well within his rights to bring about a change for the improvement of conditions by taking away land rights from one and giving them to another.

Now, what lies ahead? With modern medical care the population is increasing so fast it is estimated there will be 30,000 Marshallese, or double the present number, by 1970. Close contacts with thousands of Americans since World War II in the nuclear testing areas of Eniwetok and Bikini and with personnel at Kwajalein Island activities have whetted Marshallese appetites for much more than fish and coconuts. How can advanced 20th century operations be conducted on land that is under a stone age tenure system and where the smallest dispute gets into the raging storms of inter-national politics at the United Nations? Time alone will tell.

MALAITA ISLAND LANDSCAPE

Edwin Doran Jr.

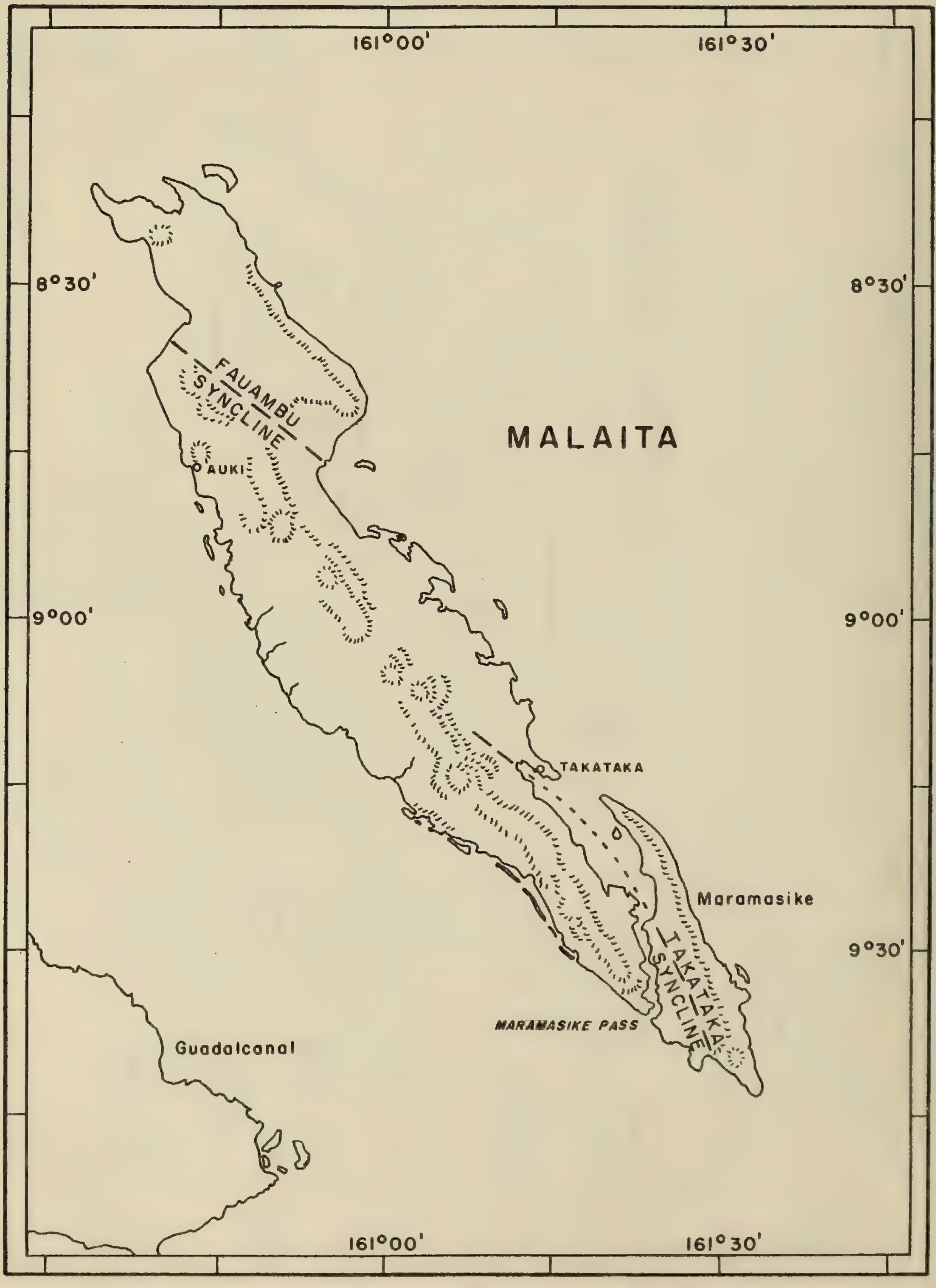
The contrast betwen the low atolls of Micronesia and the rugged mountainous islands of the Solomons is immense (Fig.6). Malaita is 120 miles long by over 20 miles in breadth, and elevations of two to four thousand feet are typical along the crests of its northwest-southeast trending ridges (Fig.8). Downfolds of the rocks are reflected in somewhat lower elevations in the Fauambu and Takataka Synclines, part of the latter forming Maramasike Passage between the island of the same name and Malaita. More subdued terrain develops on the interior areas of volcanic rocks, but the surrounding limestones and chalks are crumpled into folds and dissected into jagged ridges following the strike of the folds. Limited areas of coastal plain are developed on alluvial outwash or raised coral reefs.

Few climate records exist in this area, but the luxuriant growth of tropical rainforest covering almost the entire island is ample evidence of rainfall well over 100 inches. Much of the precipitation quickly disappears below the surface in porous limestone areas, however, and stream beds are said to be choked with boulders and even dry except immediately following heavy rains.

It is evident that a large, well-watered island such as Malaita could be expected to support many times the population of the sparse atolls far to the north - and indeed it does. On the other hand crude population density is misleading in an area of rugged and at times barren terrain, particularly when edaphic conditions also may be unfavorable to agriculture. An obvious first requirement toward appreciating the true potentiality of Malaita for support of its inhabitants and for an understanding of

its present and potential problems of land tenure lies in an accurate measurement of the extent, distribution, and quality of arable land.


SOLOMON ISLANDS
150°
153°
156°
159°
162°
3°
6°
9°
New Ireland
New Britain
New Guinea
Bougainville
Choiseul
Santa Isabel
New Georgia
Malaita
Guadalcanal
San Cristóbal


161°00'
161°30'
8°30'
8°30'
FAUAMBU
SYNCLINE
MALAITA
AUKI
9°00'
9°00'
TAKATAKA
Maramasike
TAKATAKA
SYNCLINE
9°30'
MARAMASIKE PASS
Guadalcanal
161°00'
161°30'

PROBLEMS OF LAND TENURE ON MALAITA

M. M. Townsend[1]

Malaita is a mountainous island of about 1,500 square miles with a population of just over 50,000. The total area of land available per head is thus some 20 acres: the area of cultivable land is about half the total, however. It is hard to generalize about an island on which there are still eighteen distinct dialects in five main language groups and a considerable diversity of custom, and I should like to emphasize that I am giving a personal account of impressions received as an administrator - an account by someone using a different viewpoint might differ considerably from mine.

For long the highest cohesive social group was a collection of household settlements, the head of each settlement sharing descent in the male line from a common ancestor who was buried in the area. Each group was under the loose leadership of an influential man who in some areas was self-made and in others inherited the position. Land was not owned in the sense that any person or group had freedom to allocate or dispose of it, but each individual of the descent-group had the right to use as much of the ample land accessible from his settlement as he needed - not only for gardening but also for firewood, house-site and wild or cultivated fruit. The fact that an individual cleared land (whether it was then planted with long-living fruit trees or only used briefly for gardens) gave him rights to all it produced until it was finally abandoned. Thus lasting rights could be acquired both to fruit trees and to repeatedly-used garden areas. The rare disputes within descent-groups were settled by the group's 'man of influence', and disputes between descent-groups by force of threat or occasionally by force itself.

1/ In Mr. Townsend's absence his paper was read by Dr. H. H. Aschmann, Dept. of Geography, University of California, Riverside, California.

Until the nineteenth century the Malaitan almost certainly thought of land only in terms of the use it could be put to, and not as something which could itself be owned. Gardens were established (as now) by the "slash and burn" method, with a fallow period of 6-12 years. Most men gathered fruit from trees - for the most part canarium, areca or coconut - which grew wild or which they had planted, but if a tree failed it was unusual for rights to its site to be maintained by re-planting: replacements were usually planted where the land had been cleared within recent years for gardens. Land was ample for all needs: in this connection it is possible that Malaita, which had a relatively thinly-distributed population not easily accessible from the coast, suffered less than many Pacific islands from the introduced 'killers' such as measles and tuberculosis, and that its population density at the beginning of the nineteenth century was probably less than half what it is now. By the second half of the century Europeans and others were starting to visit Malaita with some regularity, and to establish mission and trading stations. The coastal flat lands, hitherto vulnerable to canoe raids and on the whole thinly populated, became attractive to men from the interior, and (usually by arrangement with the original occupiers) many small groups established settlements there.

As the demand for copra increased from 1870 onwards, coconut trees were planted in the coastal areas (which alone were suitable) in groves of unprecedented size, and since suitable land was so restricted descendants of those who planted them saw to it that they continued to exercise their rights over the site of the grove because of the inheritance of the coconut trees upon it. The conception of a defined area being in the perpetual possession of an individual and his successors sprang up.

Further, Europeans made written agreements with Malaitans which purported to transfer land itself, and the European conception of land ownership gradually became apparent. Though the majority of plots alienated in this way were very small (up to about 10 acres) and only one (of a dozen square miles) was of real importance to the people of an area, the fact that the soil itself might be permanently alienated had (and continues to have) enormous impact on the Malaitans, and since the first World War a number of transfers between Malaitans have taken place in which both parties fully intended well-defined areas of land and not merely rights in them to pass.

Thus for forty years or more the number of Malaitans thinking of land as such, as well as of what it could produce, has been increasing. However, until very recently the demand for ownership was very limited, because the demand for money and the area on which the only cash crop (copra) could be produced were themselves limited. During the second World War many Malaitans served with the allied forces and came to appreciate a much wider variety of imported goods, with the result that a large proportion of the people either have graduated, or are in a condition to graduate, to a money economy. In addition the planting of rice and cacao, to provide the largest possible number of peasant farmers with a cash income, was encouraged by the administration, and is now being undertaken on quite a wide scale. While ownership of small groups of trees was recognized in earlier times, and the continued use of cleared land for food crops was acknowledged, a different concept began to develop when land was cleared and used for economic crops such as rice, and economic trees such as coconuts and cocoa in large numbers. Land began to have an economic as well as a subsistence value.

To many Malaitans the traditional system of all the members of a large group holding rights within the same tract is now most unsatisfactory. The young, energetic and ambitious man is unwilling to work, or even to organize the work of a group, in establishing a grazing area for cattle or a new plot of cacao, if the bulk of the proceeds from the sale of produce has to be shared with a score of relatives, some of whom may even have had to be bribed to allow permanent improvement of the land to take place at all. For its part the administration, though impartial, is anxious for the welfare of the Malaitans, and has found that the larger the group undertaking a project the greater the inefficiency and risk of failure: even a well-established coconut grove is likely to suffer if more than an elementary family holds rights to it.

The 1957 report of the Special Lands Commissioner Mr. C. H. Allan recommended that where conditions demand it the evolution of a modern system of tenure by individuals should be encouraged. The term 'individual' in this instance extended to well-defined groups acting through trustees in order that there might be nothing to prevent a traditional group establishing ownership more comprehensive than its original rights provided it could agree on its membership. Legislation now enacted provides for minor rights in an area to be extinguished on payment of fair compensation, for the settlement of disputes, and for the registration of titles. There is however no intention of forcing the pace: the transition will be gradual since claims for registration will be dealt with as they arise. For some time to come most land on Malaita will continue to be subject to the traditional system, though there is little doubt that once claims are being dealt with smoothly and consistently, and the advantages of acquiring individual title are widely apparent, the demand for it will rise progressively.

Of the obstacles to the making and consideration of claims the first is purely physical - the fact that because so much land has been available in relation to the needs of the people it has never been necessary to establish exact limits. The second is more serious - the opposition of some members of a group to any of its members claiming registration of part of its original area which he has developed. The main grounds of objection are likely to be:

(a) that 'custom' should not be changed - there are still many on Malaita who hold that custom is immutable, despite all evidence to the contrary;

(b) that members of the group who are by inclination or through no fault of their own less active will no longer be able to profit from work done by the young and ambitious;

(c) that the group at present cares well for its aged, and that once members are allowed to become wholly independent of the group many of the aged will be left destitute;

(d) that land to which an individual holds title may be sold or mortgaged for the private profit of the title-holder, leaving his family destitute and allowing persons of whom the group does not approve possession of group land.

It is impossible to have much sympathy with those who base their objections on the first two grounds, but the third poses a problem which will have to be faced, and to which the Malaita Council, which has provided valuable advice in the past, may be able to suggest a solution. It is unlikely that the economy will be able within the near future to support any extensive alternative system to provide for the care of the indigent aged.

Objection on the last ground is also valid: in such countries as India and the Gold Coast (now Ghana) the mortgaging and sale of land led to the development of a landless class or a tenancy perpetually in debt to landlords who often behaved oppressively. The alienation of land to non-natives (including leasing) is already strictly controlled by the administration, and it only remains to devise some control over alienation to natives for part of the problem to be solved. As far as pledging land is concerned, the provision of credit is essential to the orderly economic development of the islands, which at present have no major asset other than their land and its produce. Fortunately a statutory body (the Agricultural and Industrial Loans Board) already operates a revolving fund from which loans at a low rate of interest (about 5%) are made. The Loans Board is required as a general rule to take security for its loans, and accepts titles to land, but the interest rate is low enough to enable even moderately efficient projects to pay off the mortgage in the first few years of production, so that it is unlikely that the raising of credit on land which is itself to be developed by means of the loan will lead to its alienation.

FIJI ISLANDS LANDSCAPE

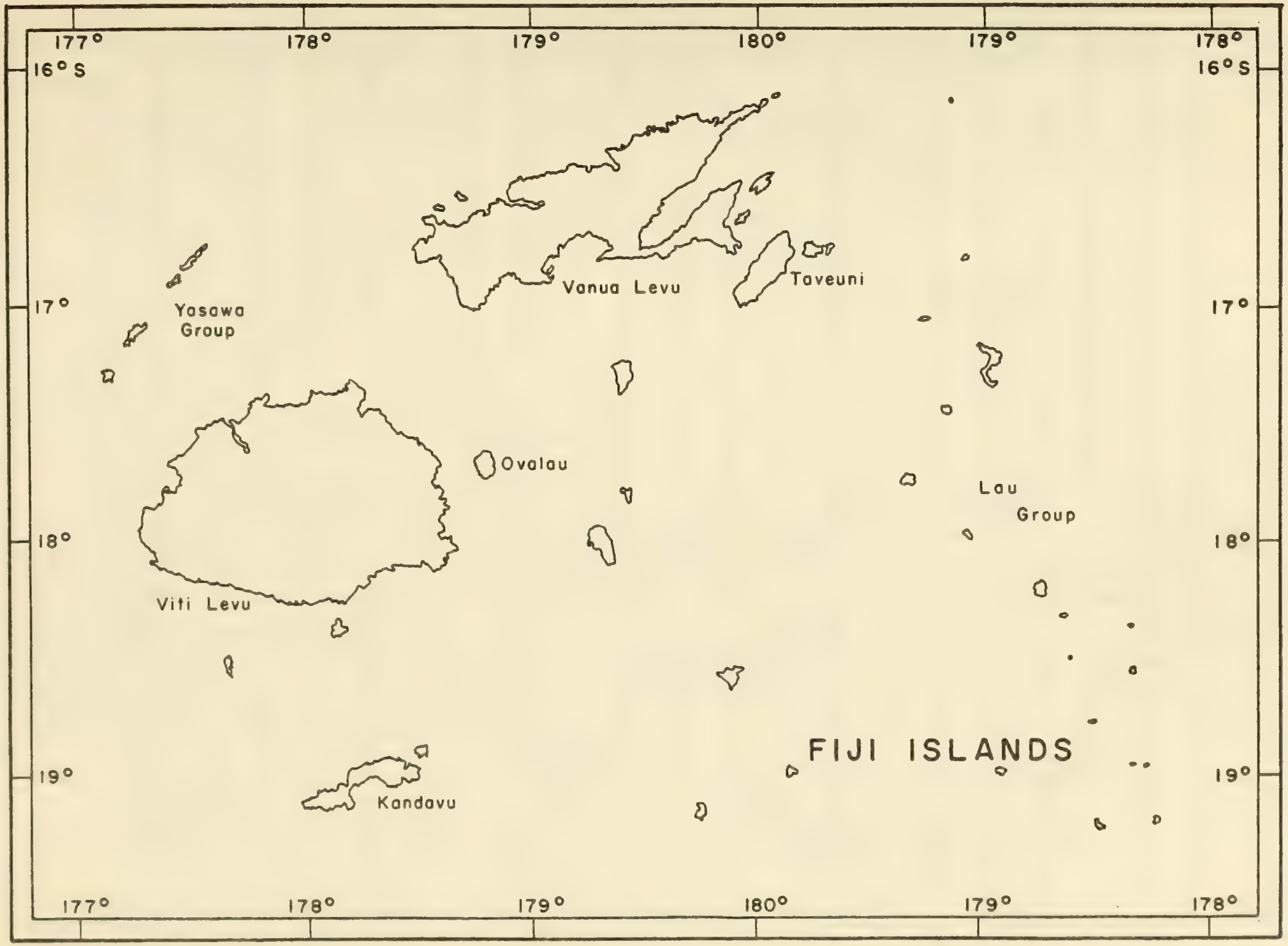
Edwin Doran Jr.

The two large and many smaller Fiji Islands are distributed over an area about 300 miles square and with their large area and rugged terrain are rather similar to the Solomons (Fig. 8). Viti Levu, with dimensions of 60 by 90 miles, is somewhat larger than Guadalcanal and has the same elevated and dissected surface (Fig. 9). Vanua Levu is similar in shape and area to Malaita. The coastal plains which form the most desirable sites for human activity are limited in area to only 11% of the two larger islands, but these are bordered by rather extensive mangrove swamps which are possibly reclaimable. Coral reefs fringe most coastlines and are strewn in profusion among the islands.

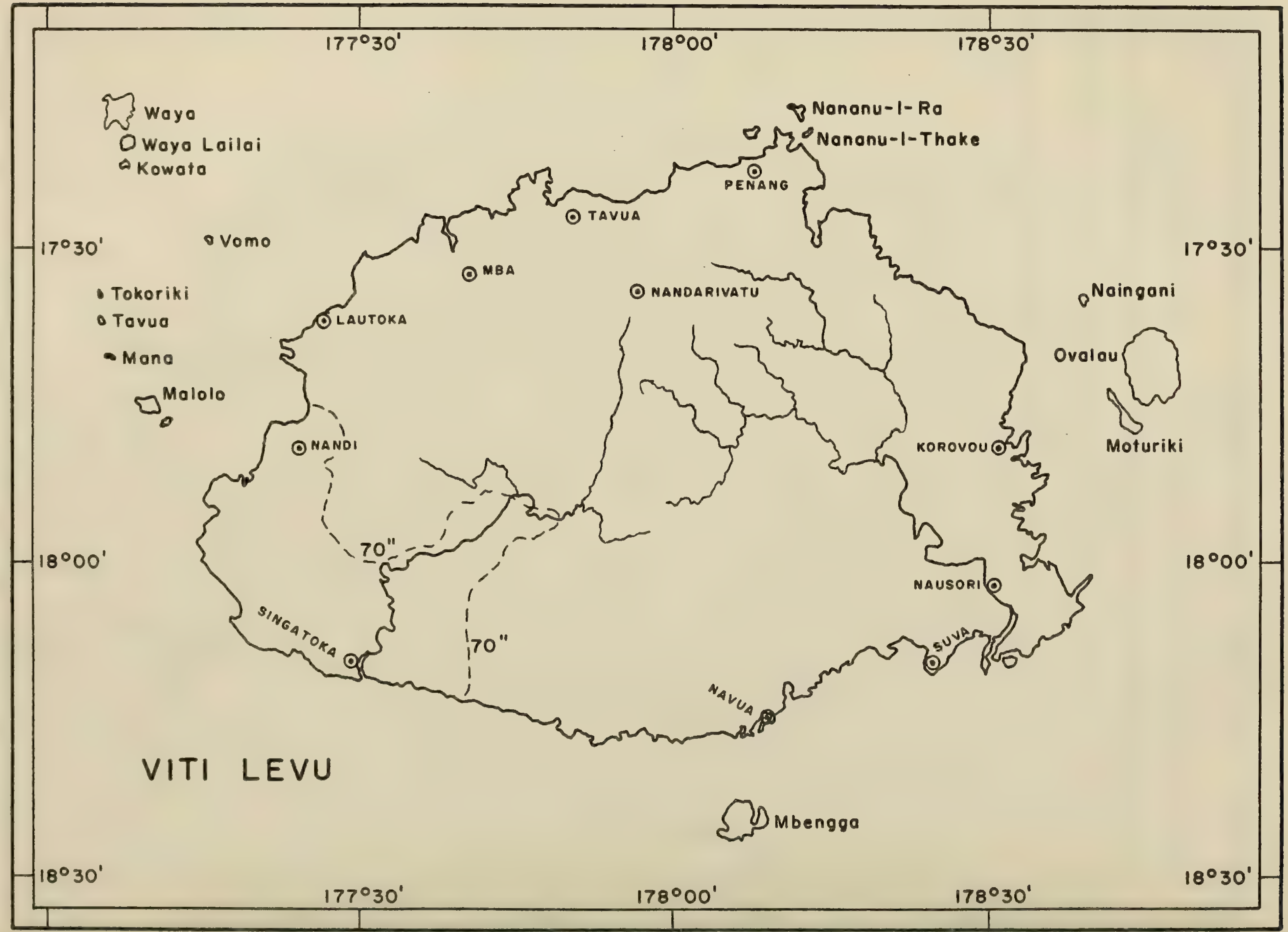
Although adequate climatic data are not available in the Solomon Islands it is evident from a comparison of vegetation that Fiji is somewhat less rainy. Considerable areas in the west and northwest of both Viti Levu and Vanua Levu receive less than 70 inches per year. It is probable that few if any areas in the larger Solomon Islands receive so little. The eastern and higher parts of Fiji, of course, have rainfall averages over 100 inches in most places, and Suva once recorded 37 inches falling during a 13-hour storm. The lower quantities in the western parts of the large islands and a marked dry season are notable assets since these also are requirements for growing sugar cane, by far the most important contribution to Fijian economy.

The distribution of precipitation is closely mirrored in the distribution of vegetation with marked contrasts between the dense and luxuriant rainforest of eastern Viti Levu and the grassy hills and fields of sugar cane in the western part of the island.

The approximate equivalence in numbers between native Fijians and the descendants of indentured Indian laborers is well known. Dominance of sugar cane agriculture by the latter, while land is owned for the most part by communal groups of the former has long been a difficult situation. Problems arising from these relationships are examined in the discourse which follows.



FIJI ISLANDS
Vanua Levu
Taveuni
Yasawa Group
Viti Levu
Ovalau
Lau Group
Kandavu
177°
178°
179°
180°
179°
178°
16° S
17°
18°
19°


177°30'
178°00'
178°30'
17°30'
18°00'
18°30'
Waya
Waya Lailai
Kowata
Vomo
Tokoriki
Tavua
Mana
Malolo
Nananu-I-Ra
Nananu-I-Thake
PENANG
TAVUA
MBA
NANDARIVATU
LAUTOKA
NANDI
70"
70"
SINGATOKA
NAVUA
SUVA
NAUSORI
KOROVOU
Naingani
Ovalau
Moturiki
Mbengga
VITI LEVU

LAND IN FIJI

R. H. Regnault[1/]

The Fiji Group consisting of some 300 islands lies mainly between the 16th and 20th parallels of southern latitude. It is confined between meridians 177E and 178W; the 180th meridian passing through the islands of Vanua Levu and Taveuni. The group covers an area of approximately 60,000 square miles and its own land mass is 7,055 square miles in extent. The two main islands, Viti Levu and Vanua Levu cover 4,011 square miles and 2,137 square miles respectively. Suva the capital city and center of Government is situated on the south east coast of Viti Levu and is 1969 miles from Sydney, and 3163 miles from Honolulu.

Viti Levu, Vanua Levu and islands near their shores are mainly of geologically recent volcanic origin. The hinterlands are of a broken nature with rugged mountain ranges rising in the centre. In the case of Viti Levu the highest point is over 4,300 feet. The islands of the Lau Group, some 200 miles east of Suva, provide a marked contrast being of limestone formation and of low relief.

To the east of the 180th meridian is Polynesia, to the west Melanesia. Fiji stands at the ethnic and geographic cross roads and the present day customs and characteristics of the indigenous Fijian reflect influences from both origins. One of the problems of the Administration today is to bring about a climate of opinion amongst Fijians to allow for greater freedom for individual action in terms of a materialistic twentieth century cash economy.

1/ Paper read for Mr. Regnault by Dr. F. H. Bauer, Dept. of Geography, San Diego State College, San Diego, California

Because of the conditions prevailing in the early 1870's Fijian Chiefs appealed to Great Britain to bring order out of chaos. On 10th October 1874 an unconditional Deed of Cession was signed and Fiji proclaimed a British possession. The unconditional vesting in the Crown of all land not the bona fide property of Europeans and not in actual use or occupation by Fijians at the time of execution of the "Deed" has been argued from that day hence. However, British policy over the years has given prescriptive validity to the principle of the inviolability of Fijian Lands.

Claims to ownership of land by Europeans and others who had entered into dealings with Fijians prior to cession were decided by a Land Claims Commission which operated between 1875 and 1900. The findings of this Commission established the bulk of present day freehold land.

The Real Property Ordinance of 1876 was enacted to control freehold land dealings. In it were provisions precluding the acceptance of any plan of land by the Registrar of Titles or by any court in the Colony if such were not endorsed by a registered surveyor. In 1877 an Ordinance to provide for the registration of Surveyors was passed. These Ordinances had far reaching effects and have been primarily responsible for the excellence of the Colony's map and plan coverage - said to be superior to that of most other countries in a comparable stage of development.

In 1880 a Native Lands Commission was set up to ascertain and define 'Mataqali' boundaries; the Mataqali being the recognized Fijian land-holding unit. It is a division of a larger social unit, the Yavusa, which in turn approximates to something between a tribe and a clan claiming descent from a common ancestor. The work of the Commission has

continued to the present time and now nearly all Mataqali ownerships have been surveyed and recorded. In late years the work of the Commission has been mainly directed to investigating and making recommendations in respect of Native land to be reserved within Mataqali holdings for exclusive Fijian use.

There are some 5,127 Mataqali (average membership 29 persons) in Fiji and they own 3,776,000 acres or 83.6% of the land in the Colony. Unalienated Fijian land is used according to custom and agricultural activity (mainly for subsistence purposes) is usually on a shifting cultivation basis. However, it must be borne in mind that nearly half of the Colony is considered unsuited for agriculture, orchard crops, grazing or productive forest.

The Colonial Office policy of preserving the customary Fijian way of life in the early days led to a shortage of paid labour and brought about the introduction of imported labour to work the plantations. Labour was firstly imported from Melanesia and secondly when that source dried up, from India. In 1879 the first shipload of Indian indentured labour arrived in Fiji. Indian labour continued to arrive in Fiji until 1916 when the indenture system ceased. Few Indians took advantage of repatriation at the termination of their contracts. These labourers were followed by Indian shopkeepers and merchants. All have multiplied accordingly and so it is today that Indians form the greatest percentage of the population.

Fiji is a multi-racial agricultural Colony whose economy is largely dependent on the production of copra, sugar and gold. In 1956 agriculture was the main occupation of 58.9% of the total occupied population.

Fiji's population at 1961 is estimated at 410,263 (171,248 Fijians, 206,819 Indians, 32,196 others - Europeans, part Europeans, Rotumans and other Pacific Islanders) and is expected to increase to 583,859 by 1971. Of the total land area of the Colony, i.e. 4,514,438 acres, Fijians hold 83.6% in customary terms and .2% in registered freehold ownership. Other freeholders are Indians 1.7%, Europeans and part Europeans 5.5%, Colonial Sugar Refining Company 1.7%, Chinese and other .7%, whilst Rotumans hold .2% in customary tenure. The balance of 6.4% is in Crown ownership.

Indian holdings are increased by way of leasing 230,000 acres from Fijians, 40,000 acres from the Crown, 50,000 acres from the Colonial Sugar Refining Co. and 30,000 acres from other freeholders. It should be noted that some 63% of the leased land is situated in the fertile and financially rewarding cane growing areas.

Equating the 1961 population figures with the following land use categories

(i) Agricultural land

(ii) Agricultural land requiring modest improvement

(iii) Land requiring major improvements

(iv) Land unsuited for permanent agriculture

we find that the acreage per capita works out at 1.76, 0.95, 2.90, 3.4 acres respectively. This is somewhat of an over simplification as it disregards, amongst other matters, Fijian ownership of 83.6% of the land in the Colony.

Whilst I have no figures with which to make similar comparisons with other Pacific territories, the following population/density figures are interesting:

Population

Fiji (1958)	-	374,284	-	53 persons per sq. mile	) very) approxi-) mately) the same) area.)
New Caledonia (1957)	-	70,747	-	10.1 " " " "	
New Hebrides (1956)	-	48,725	-	8.5 " " " "	
Kingdom of Tonga (1956)	-	58,000		232 " " " "	

Freehold land comprising as it does some 10% of the Colony is held by registered proprietors in fee simple. It can be bought, sold, mortgaged, pledged and subdivided (subject to subdivision of land and town planning considerations). There are no moral or customary restrictions on its use other than those placed on it by the individual owner himself. The Colonial Sugar Refining Co. is the largest single freehold owner and it leases out most of its lands.

Crown land is divided broadly into 4 categories:-

(a) Crownland with or without title. This is land which has come to the Crown by way of Native Grant, purchase or acquisition and totals some 85,424 acres.

(b) Crown Schedule 'A' land is that which falls to the Crown as 'ultimus haeres' on the extinction of a Mataqali and amounts to 120,000 acres.

(c) Crown Schedule 'B' land is that for which no claim was made to the 1880 Native Land Commission and accounts for approximately 88,000 acres of the poorer lands.

(d) Large areas of Crown foreshore covered in mangrove which is potentially reclaimable.

Rents from Crown land in categories (a), (b), and (d) are paid into the Colony's general revenue. Rents from Crown Schedule 'B' lands less 10% are paid to a special fund controlled by the Fijian Affairs Board for the benefit of Fijians.

Only in exceptional cases is it possible to dispose of the freehold of Crown land. Practically all alienation of Crown land is done by way of lease.

Crown leases are exceptionally popular and in many cases seem to be preferred to freehold tenure. This is hard to understand as these leases are circumscribed by numerous conditions and failure to honour them can lead to cancellation. However, rentals are modest, seldom exceeding 4% of the unimproved capital value of the land.

The Crown undertakes the provision of basic survey work for all lands in the Colony and every lot whether surveyed for residential, agricultural or any other purpose is itself connected to the basic survey system.

Most urban development has been undertaken by the Crown and nearly all towns and townships in the Colony (especially Suva) have been laid out as a result of Crown initiative. However, Crown land available for development in both urban and rural areas is now limited.

No Fijian land may be sold except to the Crown. The leasing of Fijian lands outside Reserves is controlled by the Native Lands Trust Board - a body set up under a special Ordinance with a Fijian majority divorced from Central Government agency. The leases issued by the Board contain clauses similar to the covenants of Crown leases. Finance to operate the Board's activities is obtained by diverting 25% of all rents and royalties received to the Board's revenue. Of the balance some 30% is distributed to high ranking members of the social units involved, leaving some 45% for distribution to the rank and file of the Mataqali.

In 1959 a Commission under the Chairmanship of Sir Alan Burns was appointed to enquire into the natural resources and population trends of the Colony. The Commission carried out an exhaustive investigation and

published its findings and recommendations in a comprehensive report.[1/] The Commission emphasized the impossibility of ignoring the Fijians' right to the ownership of all land other than Crown and freehold and re-affirmed that the Mataqali should continue to be the land owning unit. It also recommended that Mataqalis should be registered as corporate bodies to enable them to pledge their lands as security for loan purposes. This recommendation was not accepted by the Legislature nor was the recommendation to tax inadequately used land.

However, the Legislature has now indicated its acceptance of recommendations to implement landlord and tenant legislation, to increase the terms of agricultural leases to 60 and 99 years and to accelerate the demarcation of Native Reserves.

There is a growing awareness amongst Fijians of the advantages to be gained by the independent farmer and Government has supported the Burns Commission recommendation that this type of farmer should be encouraged. Despite the difficulties both practical and psychological, numbers of Fijians have made the break and are established as individual farmers on their own land. In these cases subsistence shifting cultivation has given way to up-to-date methods of husbandry and there are successful Fijian cane and dairy farmers in different parts of the Colony.

With the settlement of Fijian Reserve claims in sight it is hoped that land not so claimed will become more readily available for settlement. With new avenues for obtaining finance soon to be available in the Colony, it is expected that Fiji's agricultural economy will develop on a diversified farming basis and that more land to accommodate an expanding population will be made available on reasonable terms.

1/ Fiji, Legislative Council. Report of the Commission of Enquiry into the Natural Resources and Population Trends of the Colony of Fiji, 1959. /Suva/, 1960. 154 pages, Maps. (Council paper no. 1 of 1960).

TONGA ISLANDS LANDSCAPE

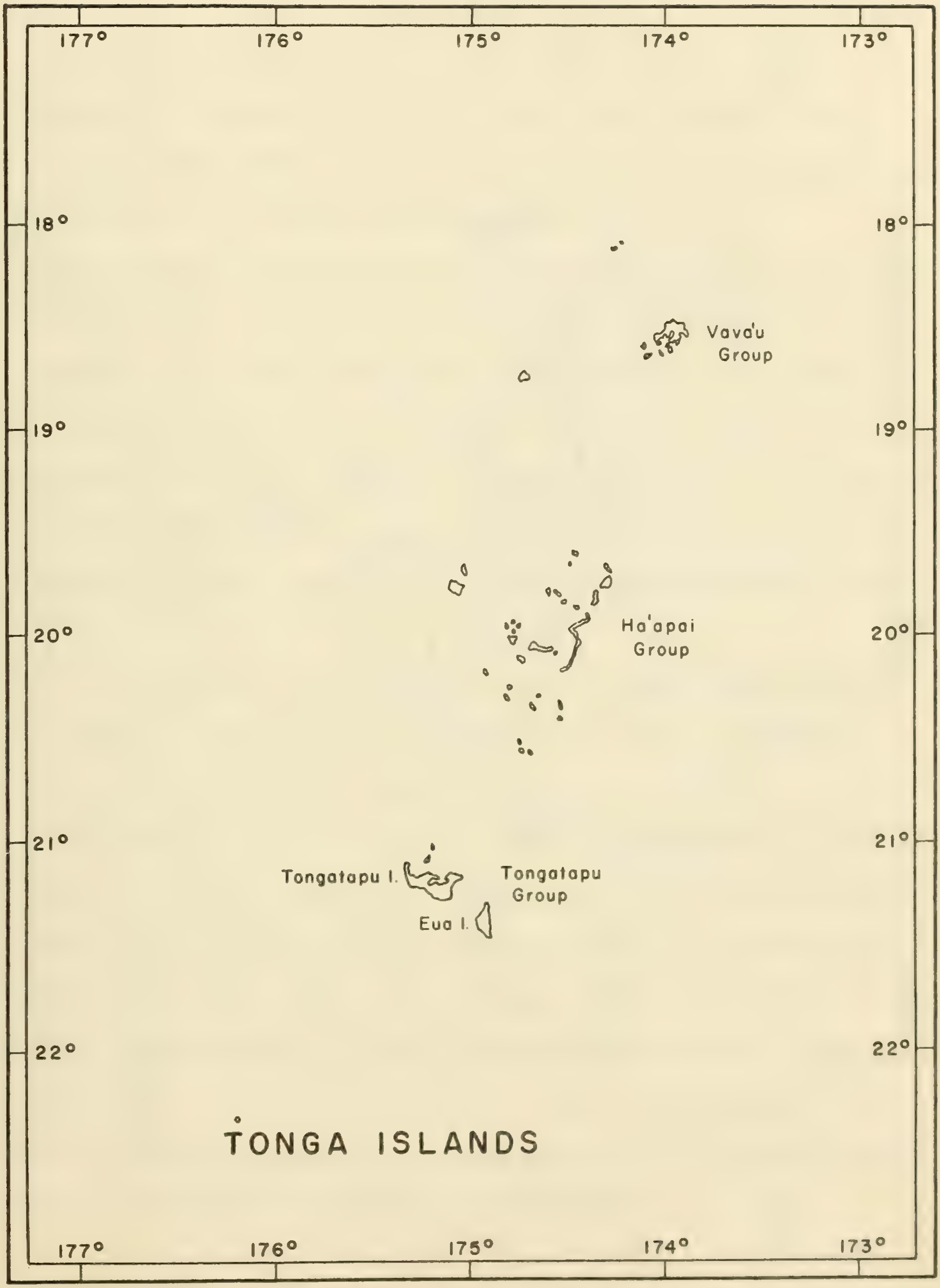
Edwin Doran Jr.

Tongatapu Island, largest of the group and seat of government, has dimensions of 9 by 18 miles and an area of about 90 square miles (Figs. 10, 11). It is representative of the easterly chain of Tongan islands which are relatively low and very largely formed of limestone, in contrast to the several active volcanic islands to westward. Southeastern Tongatapu reaches a maximum elevation of 270 feet, with precipitous coastal cliffs close at hand. From this eminence the island slopes gently northwestward. Nuku'alofa, the capital and principal city, lies on the north coast where indentations and a maze of reefs provide excellent protection for shipping.

Temperatures in Tonga are equable and pleasant, with easterly winds during much of the year. Rainfall at Nuku'alofa averages 63 inches per year and is quite dependable. Typhoons at irregular intervals are the principal interruption in a rather even climatic tenor.

Coconut palms are widely diffused and a principal aspect of vegetation, although pandanus, hibiscus, and other typical Pacific island plants are also present. Considerable portions of the island have been cleared, are used for truck crops, or may have reverted to grass or scrub.

With its unique system of government and landholding Tonga presents a most interesting facet of landholding patterns in the Pacific.


177°
176°
175°
174°
173°
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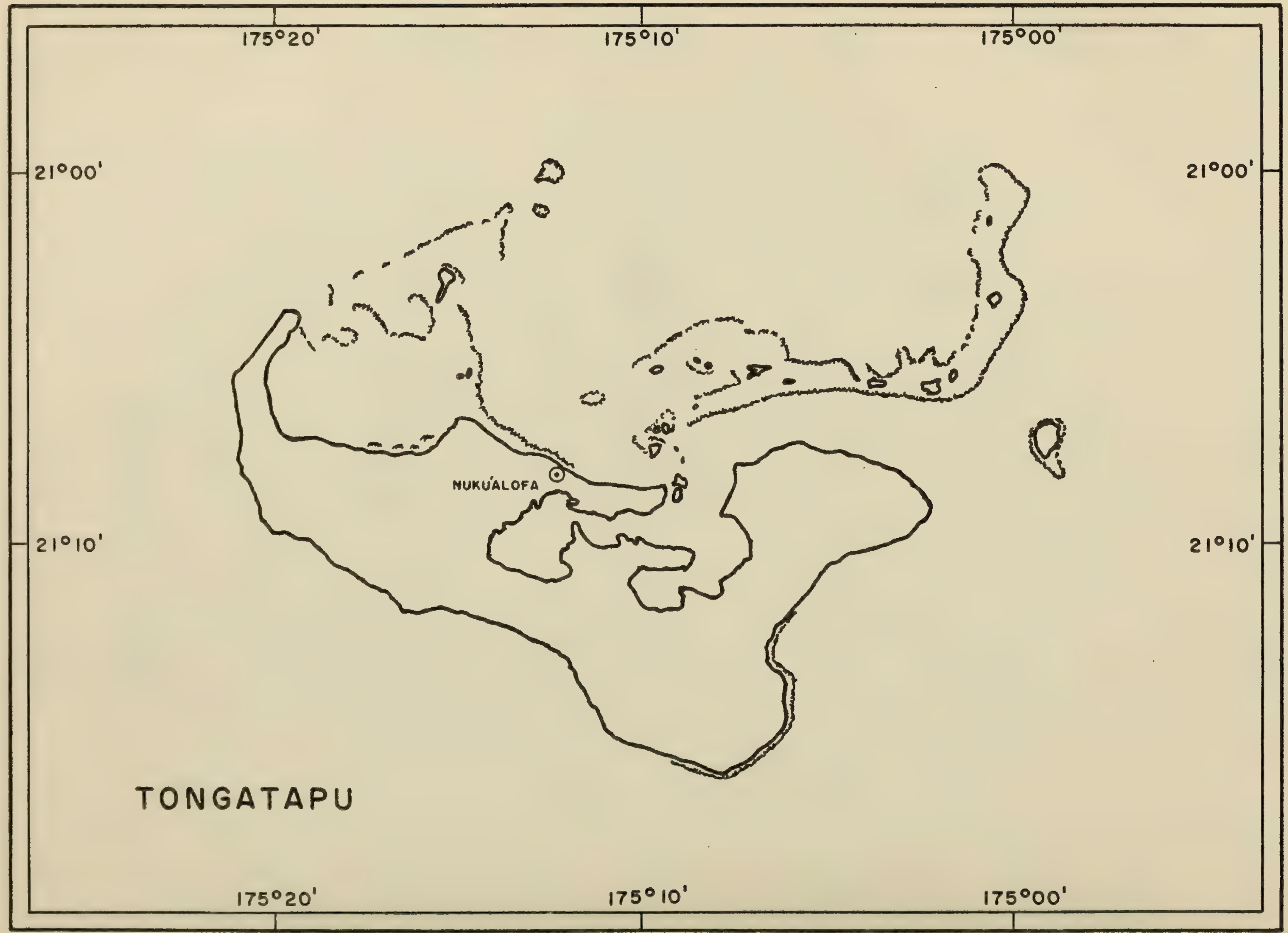
22°
Vava'u Group
Ha'apai Group
Tongatapu I.
Tongatapu Group
Eua I.
TONGA ISLANDS


175°20'
175°10'
175°00'
21°00'
21°10'
NUKU'ALOFA
TONGATAPU

LAND TENURE IN TONGA

Q. F. Pilling [1/]

The land tenure system in Tonga is a unique one, and may be considered most admirably suited to a country whose economy is based on an agricultural system operated at family level, a system where the small holder and the family group are the backbone.

To understand this one must have a knowledge of the system of rule established under the Monarch, Her Majesty Queen Salote Tupou.

Tonga is a protected state of the United Kingdom and is ruled independently under a constitutional monarchy established in 1862. The first King, George Tupou I, by strength of character and of arm, established suzerainty over Tonga and unified what had until this time been a loose alliance of a number of islands in the Tonga Group under several accepted chiefs.

With unified rule came the establishment of constitutional government modeled in miniature on that of the British Crown and Government. This has served Tonga well.

It is worth noting that there was little foreign influence on land holdings since at this stage Tonga had been open only to the educational influences of the various missions and passing New Zealand whaling fleets using the harbours for shelter and watering. It was now possible to establish the Land Control of Tonga without outside influence affecting the issue. This was done with admirable success in the framing of the Land Act, the original of which, with few amendments, has remained the charter for Land tenure of Tonga to the present day.

1/ In Mr. Pilling's absence his paper was read by Dr. Crocombe in addition to his own concluding paper.

Thus Land Tenure in Tonga is built on the concept that all land throughout the country is regarded as the property of the Crown and there is no freeholding whatsoever.

The land is divided out in 'Tofia' which are hereditary estates and, within broad limits, approximate the spheres of influence of the Chiefs before unification. There are also royal estates and government estates. From these all parties draw a nominal percentage of the poll tax of 32 shillings per year paid by each Tongan male of 16 years or over. Though these estates, of which there are just over 30, are nominally owned by the royal family, various holders of chiefly titles, and the government, nevertheless control of the land and its allocation lies with Government under the Land Act and is administered by the Cabinet of Tonga through the agency of the Minister of lands and his department.

With this picture in mind we can follow the pattern as it affects the individual and the family.

During his lifetime a poll tax payer is entitled under the Act to two statutory areas of land, 8 1/4 acres of bush land for farming and 1 rood, 24 perches as a town allotment, usually in the nearest village to his bush land. I have said "during his life time." However, in practice the law of inheritance and provision for the devolution of these allotments provides for the holder's widow to receive a lifetime interest in his bush lands when he dies. In addition the eldest son of the family normally remains with the family to assist in working his father's land and on his father's death is eventually issued the allotments. Younger brothers apply for and are granted allotment in other areas for themsleves and their families. One might conclude that the area will eventually become saturated with no more land available, and this is the case. However, the full survey of Tonga and land division

into these statutory areas is not yet complete. It is at present in the process by a contract survey of the Kingdom undertaken by a New Zealand Survey organization. It would appear that a "pressure of population on land problem" should not eventuate for some time yet.

I have mentioned that one of the happy features of land tenure in Tonga is the absence of alienation of land to foreign influences. This has been achieved by permitting only leasehold occupation of land by non-Tongans, and consequently there have been no difficulties arising through clashes of interests. This system possibly has had a retarding effect on commercial interests, importers, and business houses as there always exists an uncertainty among the business community concerning renewal of their leases. Consequently a retarding influence on building in the two main town areas of the Kingdom, the capital, Nuku'alofa, and the centre of the northern group of islands at Neiafu in Vava'u, is apparent. Originally large areas of Tongatapu, the main island in the kingdom, were leased to foreigners as coconut plantations for the production of copra. When these leases fall due and are required they can revert to the noble on whose estate they lie and are then available for sub-division and issue as tax allotments to the Tongan people. This is now happening but without any unrest or political difficulties since the terms of lease have always been understood and respected.

This I think gives a picture of the general charter or pattern of land tenure.

Now it would be appropriate to deal with actual land utilization by the individual allotment holder, who is essentially a small farmer, growing cash and food crops. The production for overseas markets is limited to copra (the main export), bananas, watermelons and pineapples. Ideally

the allotment is fully planted out in copra at 48 trees per acre giving a return of approximately half a ton per acre. Beneath the trees the farmer may grow his banana and pineapple crop for cash return. In separate patches he produces ground foods for home consumption - yam, sweet potato (kumala), manioca, and dalo. In a fallow area of the plantation he may keep a cow for providing milk for his family, and perhaps a few pigs and fowls. The latter more often than not are kept in town.

The Tongan land holder normally resides on his town allotment and journeys daily by horse or cart to his farm land, often with his family and some relations if he has a planting program for which he requires assistance. Naturally on the larger islands such as Tongatapu this may mean a journey of some miles from the home village. This is achieved by horse and cart or by motor lorry from the home village. Families with several adult sons may find that allotments issued to them are scattered some distance apart but generally an endeavour is made to keep the families in their own districts if possible and if desired.

A localized form of share-cropping also exists which has grown out of the tax allotment system. This has come about through many of the better educated people obtaining wage- or salary-earning jobs as civil servants, shop or office employees. The result is that relations or friends undertake to work their bush allotments or <u>apis</u> on a share basis. This means that the employed person receives a return from his allotment in ground foods and also a cash return on his copra as well as the cash he receives from his job. He can thus place himself in an enviable economic position in the community.

This then gives a basic impression of a type of land occupancy peculiarly suited to an island group where extensive tracts of land are not available for large scale commercial farming. In this context

success lies in production of small cash crops by small independent farmers for whom further financial and economic development lies in the increased quantity, quality and variety of such crops for export.

For this end the Land Tenure System of the Kingdom is ideally situated and administered for the indigenous people of Tonga.

COOK ISLANDS LANDSCAPE

Edwin Doran Jr.

The Southern Cook Islands are intermediate in character between the large, high, and rainy Fiji and Solomon Islands and the tiny, low, and sparse atolls of the Gilberts and Marshalls (Fig. 12). The areas of Aitutaki and Rarotonga, for example, are respectively 6 and 26 square miles. If the entire group is considered we find an interesting transition which not only presents a miniature cross-section of the types of topography to be found in the Pacific but as well illustrates the sequence of configurations to be expected with the Darwinian hypothesis of atoll formation through subsidence.

On the south Rarotonga consists consists principally of a massive core of igneous rock surrounded by a narrow fringing reef of coral (Fig. 13). This intensively dissected volcanic remnant extends upward in jagged ridges and spires to elevations over 2000 feet, the whole engirdled by a narrow coastal plain and reef. Aitutaki represents a second stage in which the old volcano has subsided while coral has grown up and out to form a barrier reef encircling a lagoon (Fig. 14). The maximum elevation is a modest 450 feet, and the rounded summit with its thick cover of reddish soil bears witness to a long period of weathering and denudation. The third stage, with the presumed volcanic core long vanished below the sea, is shown by Tongareva, a typical atoll (Fig. 15). All that remains is a thin annulus between lagoon and ocean.

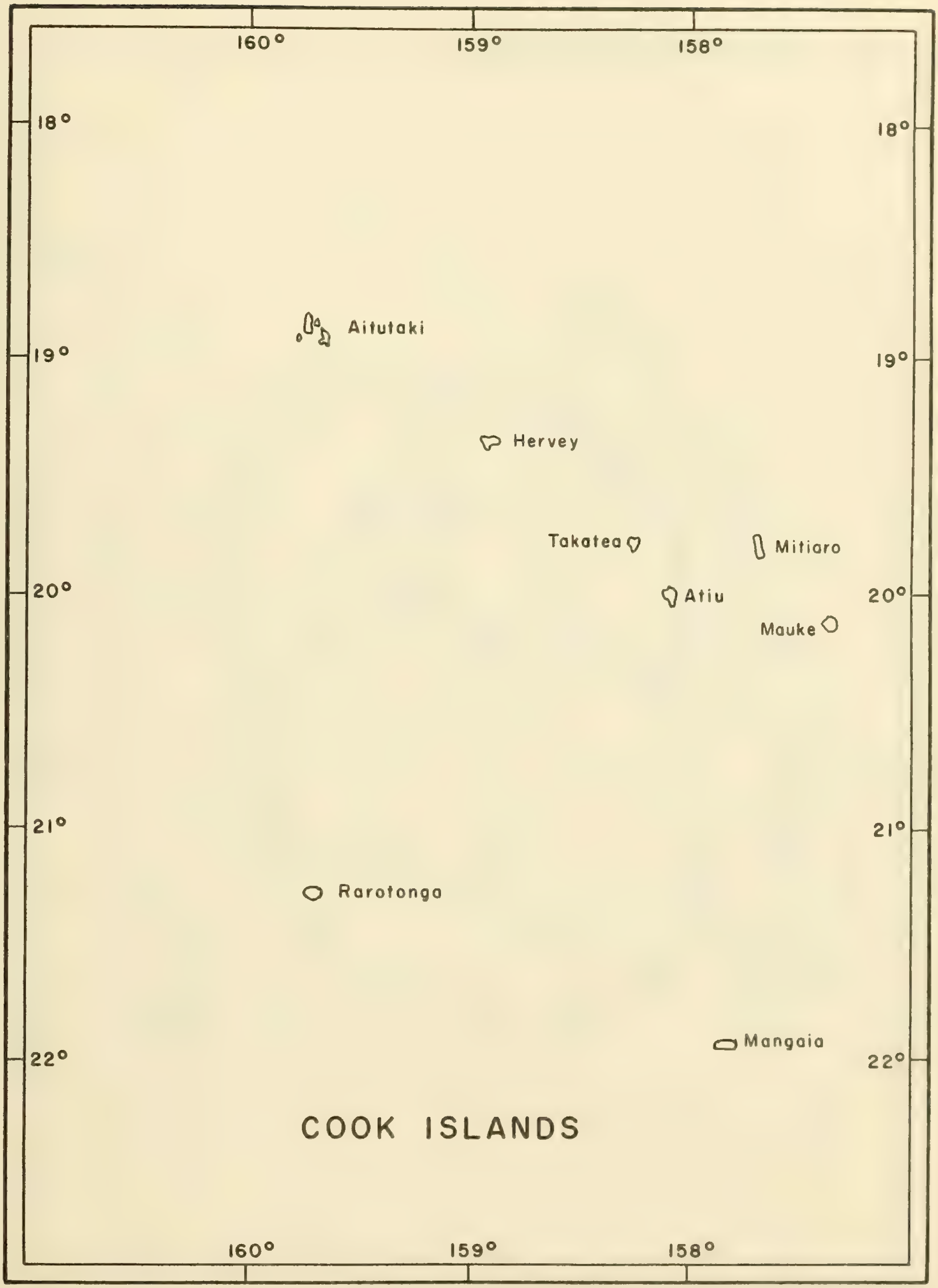
Although variability in the 60 inches of precipitation averaged at Aitutaki occasionally produces drought years with as few as 30 inches the general aspect is one of adequate rain; Rarotonga does not vary markedly from its annual average of about 80 inches. Totals greater than these

are to be found in the Northern Gilberts and Southern Marshalls, but the means for those groups taken together are not only lower but much more variable as well. The high Melanesian islands, on the contrary, average considerably more. Vegetation in the Cook Islands, in terms of luxuriance and number of species, also falls into an intermediate position.

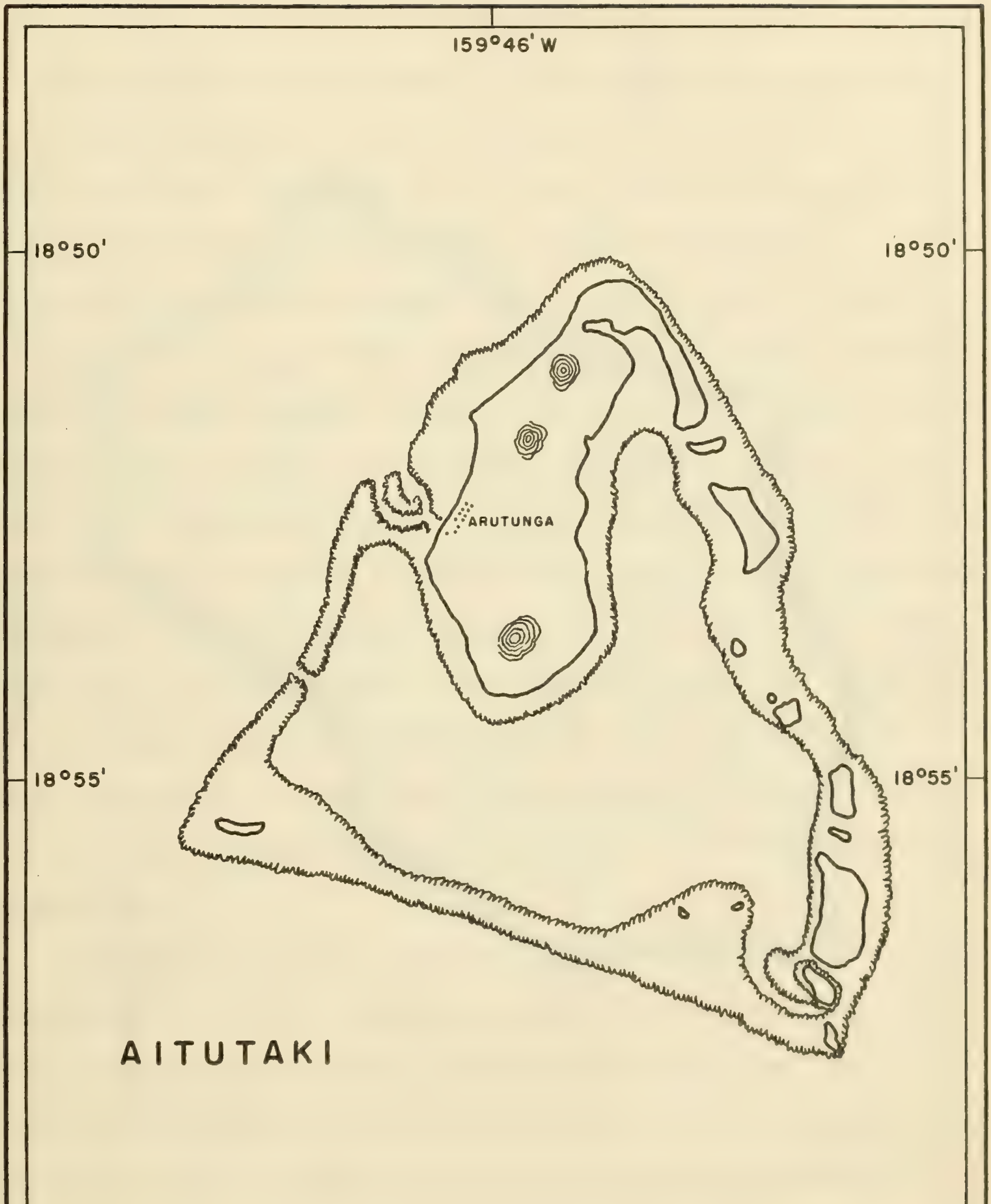
The crude population density of the Cook Islands, 85 persons per square mile, may be contrasted with figures well into the hundreds on the atolls and below 50 for the large islands. Although this density gives rise to some pressure it is not extreme, and people support themselves rather comfortably by an economy based on subsistence fishing and agriculture. The coconuts found everywhere along coastlines are utilized by all, from dignified village leaders to truants evading school. As through most of the Pacific taro is a staple which may be varied when breadfruit is in season. The physical environment, then, is one which has offered optimum conditions for development of a typical Polynesian culture.

One brief comparative note on the inter-relationships between physical landscape and population density may be cited. Where population pressures exist and where the landscape changes in character as one passes from fringing reef into the land to either interior lagoon or mountains islanders recognize the necessity of distributing the land in such fashion that all persons have access to all types of terrain. The radial pattern of land-holdings from the island center results from this recognition. The pie-shaped <u>tapere</u> of Rarotonga and the cross-islet <u>weto</u> of the Marshalls are certainly analogous shapes. They document an implicit recognition on the part of both Marshall Islanders and Cook

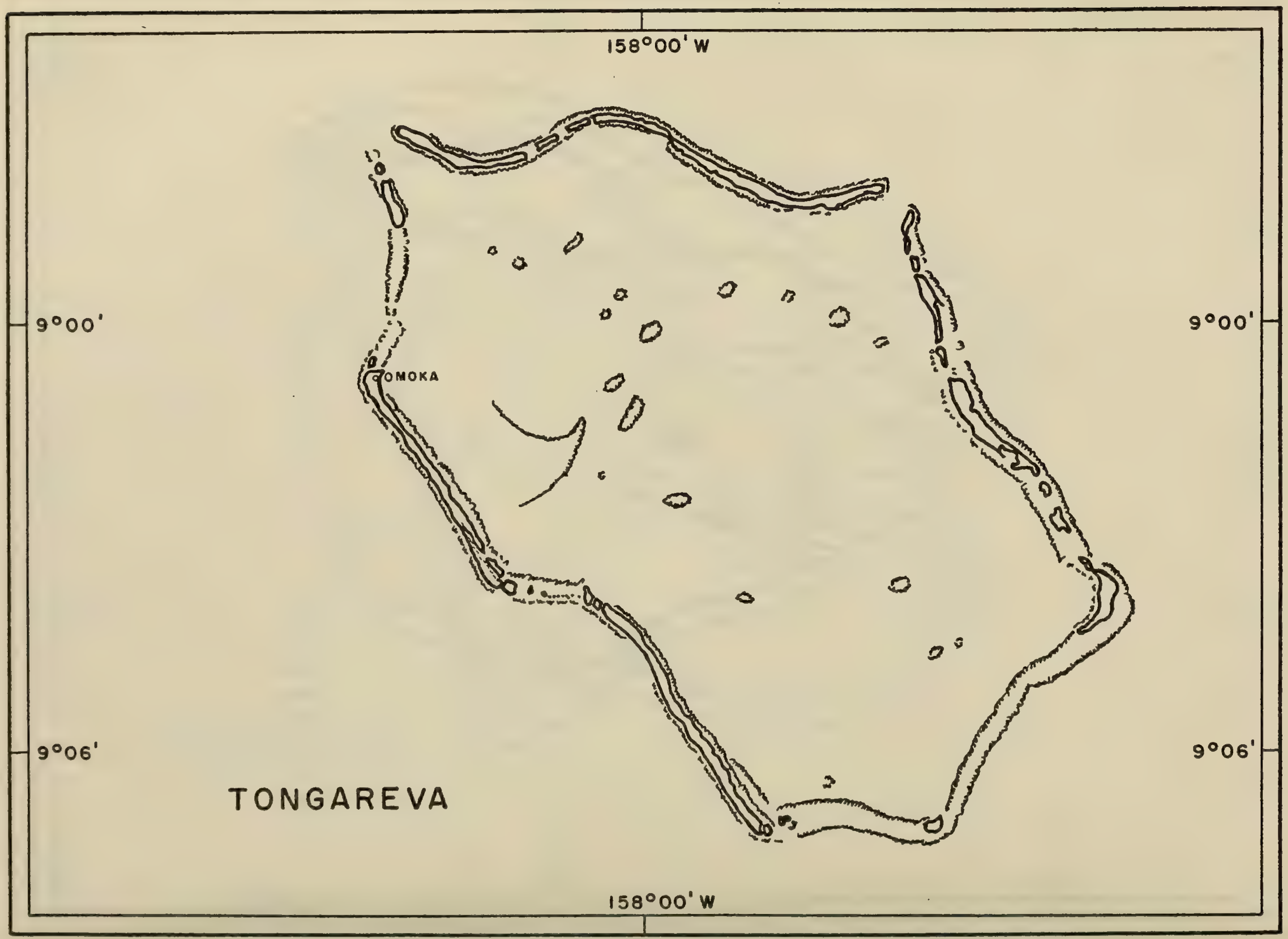
Islanders of a controlling geometry within which their respective land tenure patterns had to be developed. No such control obtains in the Solomons where the larger limits of landholdings are only roughly dictated by topography and the small square or rectangular plots under cultivation have little relation to the major aspects of island form.


160°
159°
158°
18°
19°
20°
21°
22°
Aitutaki
Hervey
Takatea
Mitiaro
Atiu
Mauke
Rarotonga
Mangaia
COOK ISLANDS

159°50'
159°45'
21°10'
21°10'
AVATIU
AVARUA
21°15'
21°15'
RAROTONGA
159°50'
159°45'



159°46' W
18°50'
18°50'
ARUTUNGA
18°55'
18°55'
AITUTAKI
19°00'
19°00'
159°46' W


158°00' W
9°00'
9°00'
OMOKA
9°06'
9°06'
TONGAREVA
158°00' W

LAND TENURE IN THE COOK ISLANDS 1/

R. G. Crocombe

As in other parts of Polynesia, the indigenous land tenure system of the Cook Islands was intimately related to its social organization - so much so that a knowledge of the social system is an essential prerequisite to the understanding of the system of land tenure.

The social system was segmentary in structure and had a strong patrilineal bias. Each minimal segment consisted of a single household headed by an elder (metua). It was joined with other related households to form a minor lineage under a subchief (rangatira or komono) - that elder among them who was senior by descent. Related and contiguous minor lineages were in turn connected to form a major lineage under the headship of a chief (mataiapo) - ideally the "first-born of the first-born" from the lineage founder. Finally major lineages were united for certain purposes under the leadership of the high chief (ariki), whose rank was paramount and whose descent was traced from the gods. Particular land rights lay with the respective groups at the various levels of segmentation.

Land rights held at the tribal level were relatively few. In peacetime there was a right of access throughout the tribal territory, provided known pathways were used and the activities were legitimate. The high chief, as head of the tribe, could impose a customary prohibition (ra'ui) on the use of particular produce throughout the tribal area in

1/ The atolls of the Northern Cook Group, which account for 14% of the total land area and 15% of the population of the whole Group, have tenure systems which differ in some significant details from those of the rest of the Group and have been omitted from this analysis.

order to conserve it for a time of shortage or a forthcoming feast. He could require that foodstuffs from tribal lands be provided for certain tribal ceremonies. Some lands belonged to the tribe as a whole and were the special responsibility of its high chief. These were the meeting places (koutu) of the tribe, and its religious centre (marae).

Each major lineage occupied a block of land known as a tapere. The tapere was almost invariably wedge-shaped - the boundaries beginning as defined points on the outer reef and running inland to enclose an ever-narrowing strip of land until they converged at a point in or near the centre of the island. As a result of this pattern of division and of the generally uniform topography of the islands, each major lineage had access to every category of soil type and land surface that the island had to offer - from the (usually) mountainous interior where forest products were collected, through the fertile valleys where the major food crops were grown, across the rocky coastal strip (makatea), to the ubiquitous lagoon and fringing reef.

In most instances the occupying major lineage was divided into several minor lineages, and the various lands were subdivided among them. Once so allocated the rights of the major lineage were limited to three - a symbolic right to regard the whole tapere as its own, the right of reversion in the event of any minor lineage becoming extinct, and the right to participate in deliberations involving the tapere lands as a whole. The lands were allocated among the minor lineages in such a way as to ensure that each had an adequate share of all the major categories of land and was thus virtually self-sufficient in so far as subsistence was concerned. While the lagoon waters were usually not divided within the major lineages, particular minor lineages had exclusive rights to fish weirs which they had constructed. Within each minor

lineage there were further subdivisions among the various branches (kiato) and within the component households (kainga tangata) of each of them. The whole of the lands were not so divided, but generally only the taro swamps, cropping lands, and areas planted with the more valuable trees.

The rights of any individual in the lands of any group were dependent on his membership of or relationship to that group, and his social status within it. An individual's connection with any particular portion of land and with the minor lineage or segment of it to which that land was allocated fell into one of the following four categories.

Firstly, there were the rights of persons who lived in a lineage and derived their right directly from some other person (usually their father) who also belonged to that lineage. These we will refer to as primary members of the lineage. Primary members held primary rights to the land - i.e. they could plant and harvest as of right.

Secondly, there were the rights of persons who had been primary members of a lineage but had subsequently (usually in the event of marriage) left to join another lineage. Their connection with their lineage of orientation was still recognized on certain occasions (particularly in the event of feasts in connection with life crises) and they could return to that lineage if due to death of the spouse or other misfortune they wished to do so. Sometimes when a high-ranking woman married out, her lineage set aside a special portion of land for her personal use, but with this exception, her right to actively use the lands of her born lineage was contingent on her return there or on their express permission. The same applied to a man who married uxorilocally. Such persons will be referred to as contingent members of the lineage, and their rights to the lineage lands will be referred to as contingent rights.

Thirdly, there were the rights of the children of contingent members of the lineage. Such children had the right to participate in certain activities in the lineage of that parent, and could expect support and assistance from them in times of crisis. Adoption was very common, and the most common direction of adoption was back to the lineage of that parent who had shifted her (or his) residence at the time of marriage.[1] We shall refer to such persons as secondary members of the lineage concerned, and will speak of their rights to its land as potential rights, for while it was generally accepted that they would be admitted to that lineage if they wished to join it, and could thereby gain primary membership of it, they did not under normal circumstances plant there while residing in another lineage. To a lesser degree, the children of secondary members of a lineage were themselves secondary members, and they also had a potential, but markedly weaker, right to the land. They will be referred to as distant secondary members. In the event of dire necessity there was no limit to the lengths one could trace secondary affiliations of this sort, but in practice they were seldom revived to the extent of exercising land rights.

Fourthly, there were rights of persons who resided in a lineage but were not primary members of it. Most significant, of course, were the wives of primary members, whose connection with the lineage was conditional on the continuation of the marriage, or the approval of the lineage if the other spouse died. Also there were in some cases refugees, captives, or others who resided with the lineage but who had no close kinship connection with it. These persons will be grouped together as

1/ If adopted back one thereupon usually became a primary member of the lineage of adoption.

permissive members of the lineage, as persons holding permissive rights to its lands. Such rights could not be transmitted and their maximum duration was accordingly the life-time of the holder.

The advent of the Europeans resulted in major demographic and social adjustments. With the exception of the fact that women came to be accepted as title-holders, there were no significant changes in land custom, though there were marked changes in the relative incidence of particular means of acquiring land rights. Largely by a process of uxorilocal marriages the port lineages became larger and those in the more isolated villages became relatively smaller. By the process of reversion, the rights of groups which died out in the epidemics fell to the holders of the higher titles who thus accumulated relatively large tracts. By encouraging uxorilocal marriages to their women, and judicious virilocal marriages with their men, the high chiefs were often able to acquire sundry junior titles and consequently the lands that went with them. The relative power of the high chiefs over the land was thereby enhanced and was reflected in increased demands for tribute from the lower social orders. There was some leasing of vacant land by the high chiefs to Europeans, but both the indigenous people and the mission opposed foreign settlement and permanent alienation was prohibited throughout.

In 1901 the Cook Islands were annexed to New Zealand. The New Zealand Government established a Land Court on the lines of the New Zealand Maori Land Court with the aim of making such lands as were not actively used by the islanders available for European settlement and increasing production from the lands used by islanders by individualizing title and "freeing" the commoners from the control of the chiefs. The former ambition was never realized and by 1910 that part of the policy

had been abandoned. The Land Court set about investigating title to the various lands, but due to there having been long periods without any judge, only about half the total land area of the group has been investigated to date. Owing to a misunderstanding by the Court of the significance of lineage affiliation in determining ownership of and succession to land rights, it awards title to all the children of a previous owner with the result that excessive fragmentation of title has occurred. Moreover, as equal rights are thus awarded to persons who are not primary members of the lineages concerned, and as the social status of the leaders of the various segments is not recognized by the Court in relation to land rights, there is no effective leadership of these rapidly increasing and heterogeneous groups of "owners" of each section. As may be expected, the work of the Land Court has not resulted in the increased per capita output of primary produce which had been hoped for.

In 1946 a scheme was introduced whereby a co-owner could be granted exclusive rights of occupation to a particular portion of the lands in which he held rights, for the purpose of planting long-term cash crops. Unlike the earlier changes in the tenure system which were imposed without consultation, this change was brought about after considerable discussion with indigenous leaders. At the time of its introduction it was supplemented by a scheme of agricultural credit together with technical equipment, skilled personnel and organized marketing facilities. This innovation has resulted in land under the scheme being the most intensively and productively used in the group, and while it takes up less than one per cent of the land area of the group, production from it now constitutes the largest single source of primary income and brings in approximately fifty per cent of the total income from agricultural production. The success of this scheme and the method of its introduction and implementation provides a pointer to the pattern of future agrarian reform in the Cook Islands.

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